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Tang et al.

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(54) **UPDATING IDENTIFICATION DATA IN AUTOMATED USER-IDENTIFICATION SYSTEMS**

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G06V 40/12 (2022.01)
G06F 18/23 (2023.01)

(52) **U.S. Cl.**
CPC ***G06V 40/50*** (2022.01); ***G06F 18/23*** (2023.01); ***G06V 40/1347*** (2022.01); ***G06V 40/1365*** (2022.01)

(58) **Field of Classification Search**
CPC G06F 18/23; G06F 18/23213; G06F 18/24; G06F 16/35; G06F 21/32; G06F 16/906; G06N 3/08; G06N 20/00; G06N 3/45; G06V 10/82; G06V 10/762; G06V 40/172; G06V 40/1365; G06V 40/50; G06V 40/1347
See application file for complete search history.

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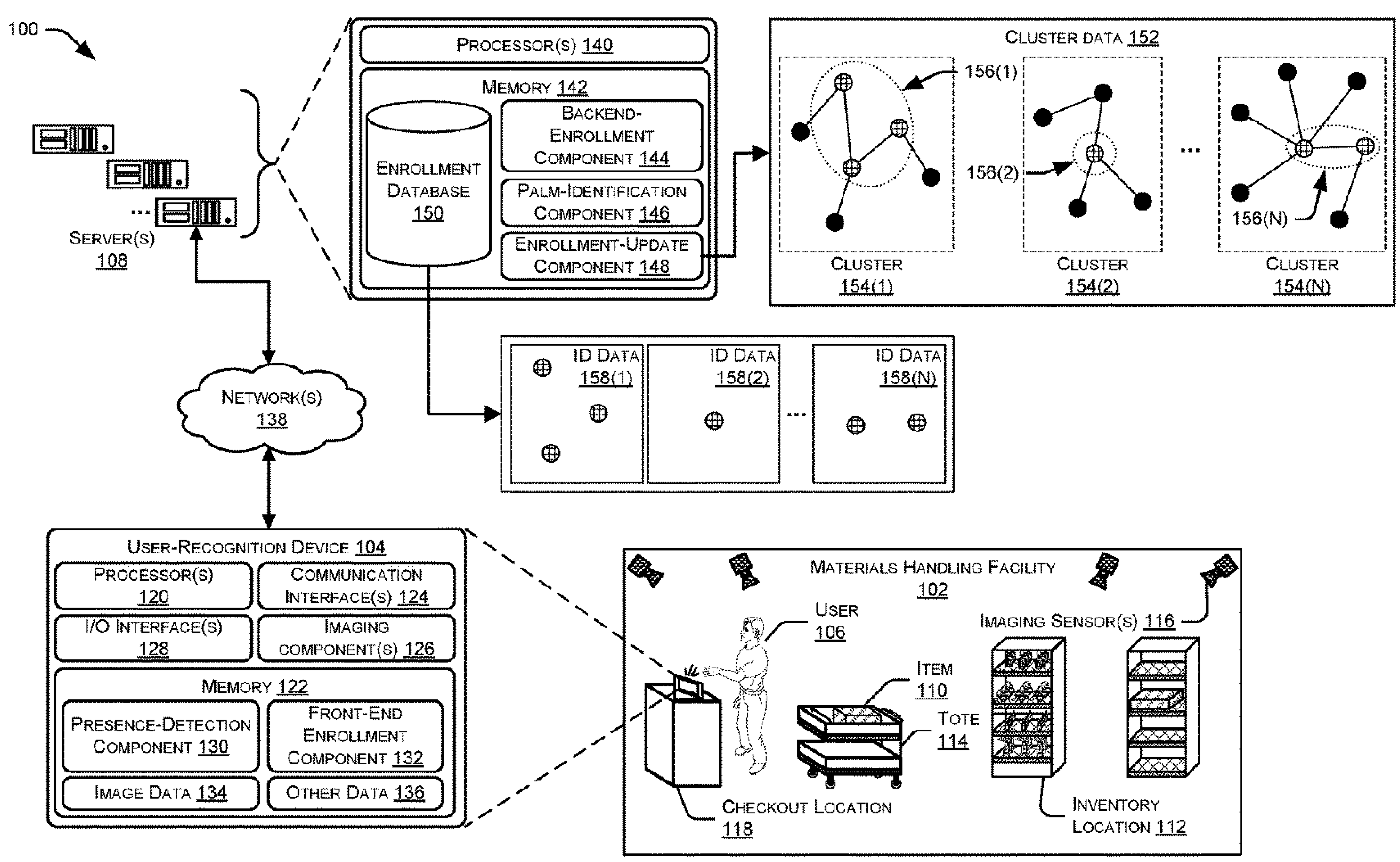
(57) **ABSTRACT**

This disclosure describes techniques for identifying users that are enrolled for use of a user-recognition system and updating identification data of these users over time. To enroll in the user-recognition system, the user may initially scan his or her palm. The resulting image data may later be used when the user requests to be identified by the system by again scanning his or her palm. However, because the characteristics of user palms may change over the time, the user-recognition system may periodically perform processes for updating the identification data stored in association with the user in order to maintain or increase an accuracy of the user-recognition system.

20 Claims, 13 Drawing Sheets



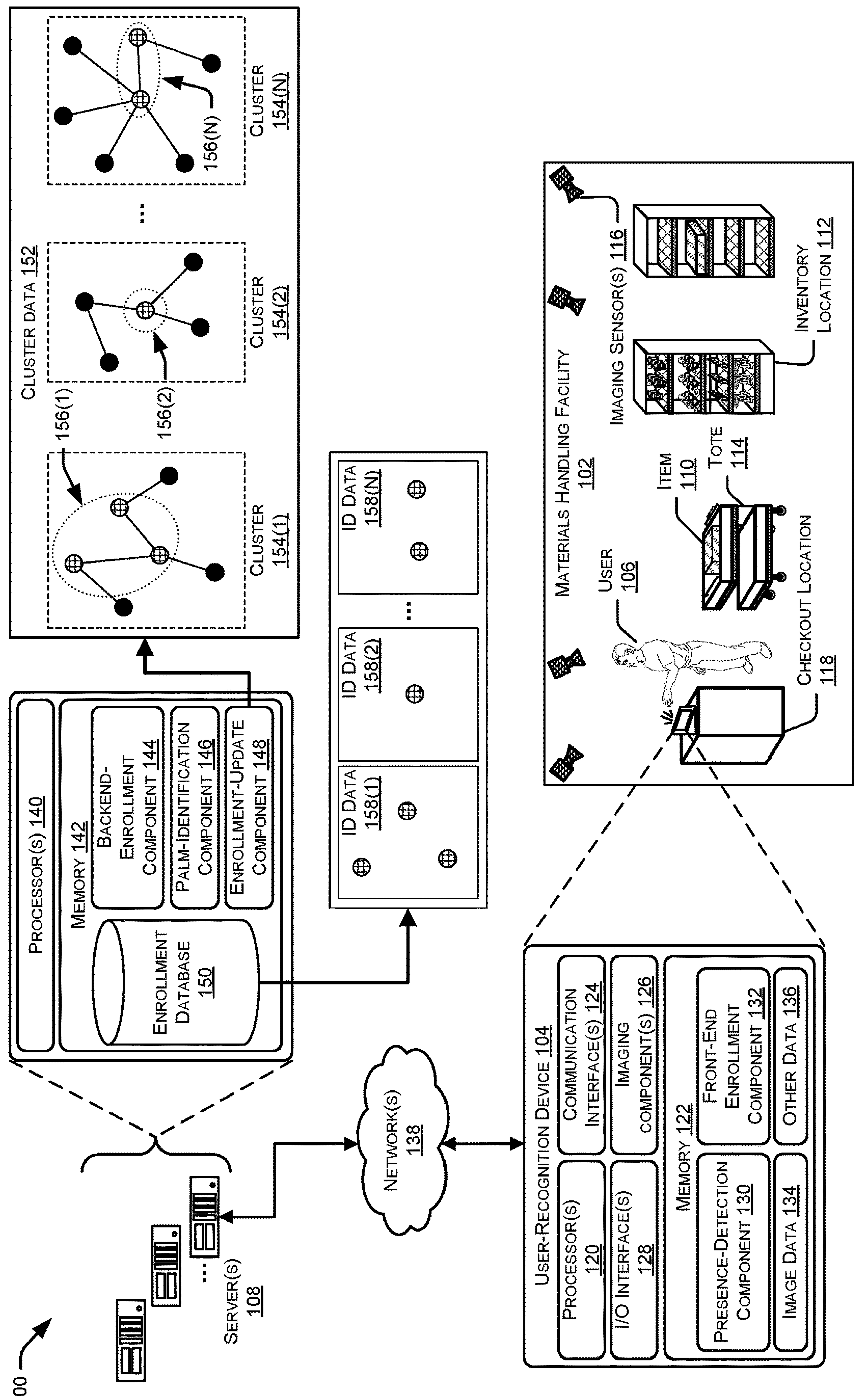

100
Server(s) 108
Processor(s) 140
Memory 142
Enrollment Database 150
Backend-Enrollment Component 144
Palm-Identification Component 146
Enrollment-Update Component 148
Cluster data 152
156(1)
156(2)
156(N)
Cluster 154(1)
Cluster 154(2)
Cluster 154(N)
ID Data 158(1)
ID Data 158(2)
ID Data 158(N)
Network(s) 138
User-Recognition Device 104
Processor(s) 120
Communication Interface(s) 124
I/O Interface(s) 128
Imaging Component(s) 126
Memory 122
Presence-Detection Component 130
Front-End Enrollment Component 132
Image Data 134
Other Data 136
Materials Handling Facility 102
User 106
Item 110
Tote 114
Imaging Sensor(s) 116
Inventory Location 112
Checkout Location 118

FIG. 1

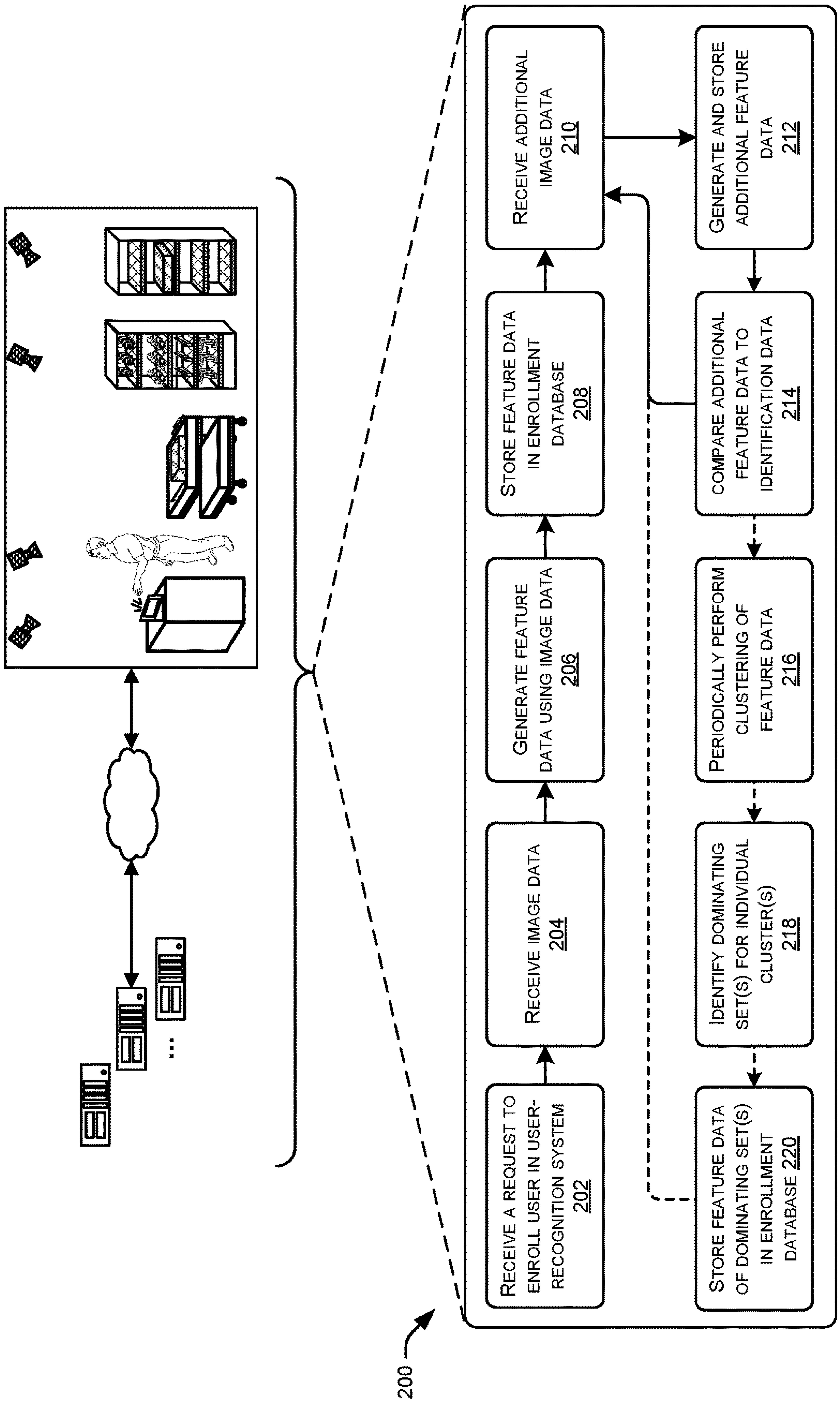

200
RECEIVE A REQUEST TO ENROLL USER IN USER-RECOGNITION SYSTEM 202
RECEIVE IMAGE DATA 204
GENERATE FEATURE DATA USING IMAGE DATA 206
STORE FEATURE DATA IN ENROLLMENT DATABASE 208
RECEIVE ADDITIONAL IMAGE DATA 210
GENERATE AND STORE ADDITIONAL FEATURE DATA 212
COMPARE ADDITIONAL FEATURE DATA TO IDENTIFICATION DATA 214
PERIODICALLY PERFORM CLUSTERING OF FEATURE DATA 216
IDENTIFY DOMINATING SET(S) FOR INDIVIDUAL CLUSTER(S) 218
STORE FEATURE DATA OF DOMINATING SET(S) IN ENROLLMENT DATABASE 220

FIG. 2

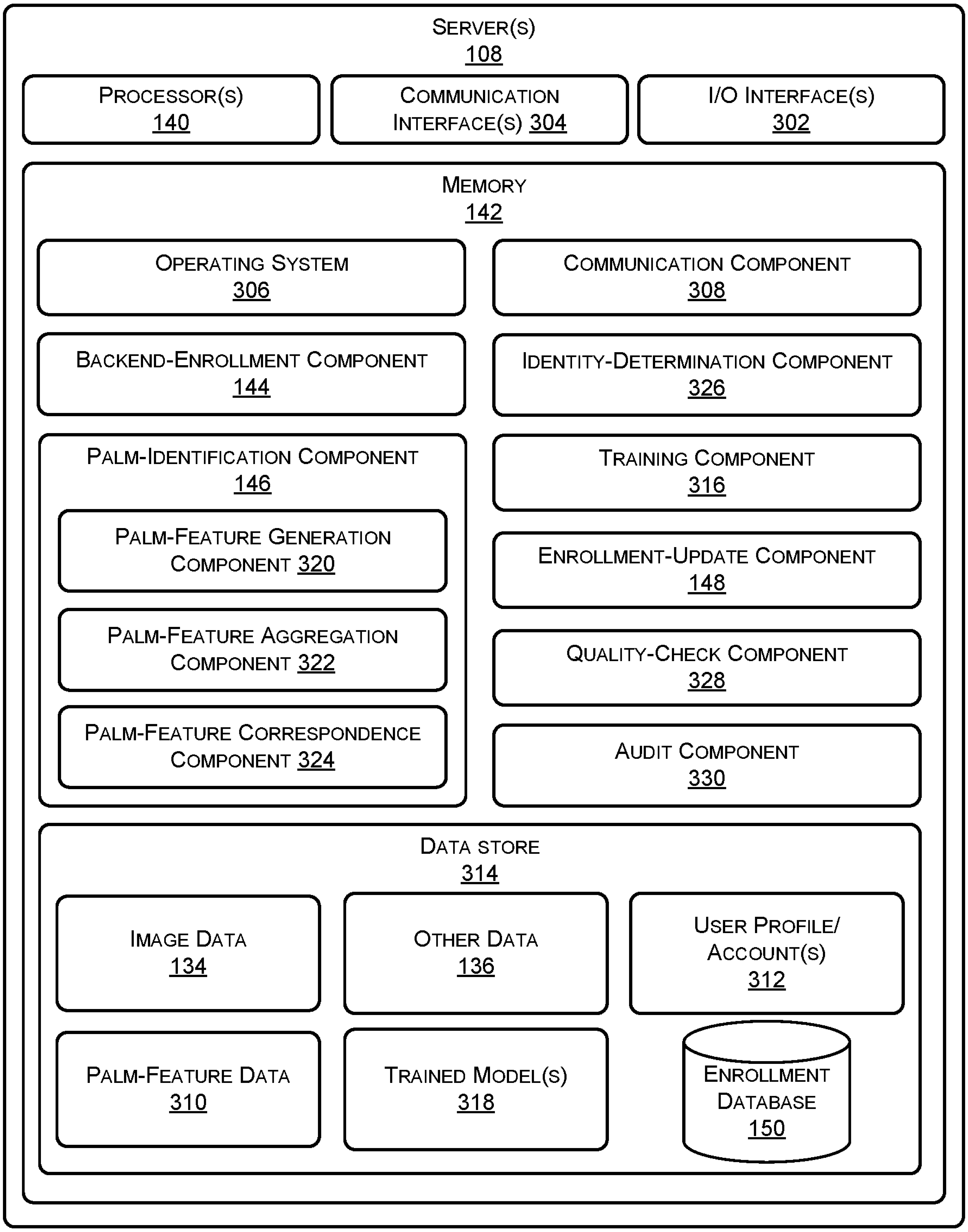

SERVER(S) 108
PROCESSOR(S) 140
COMMUNICATION INTERFACE(S) 304
I/O INTERFACE(S) 302
MEMORY 142
OPERATING SYSTEM 306
COMMUNICATION COMPONENT 308
BACKEND-ENROLLMENT COMPONENT 144
IDENTITY-DETERMINATION COMPONENT 326
PALM-IDENTIFICATION COMPONENT 146
PALM-FEATURE GENERATION COMPONENT 320
PALM-FEATURE AGGREGATION COMPONENT 322
PALM-FEATURE CORRESPONDENCE COMPONENT 324
TRAINING COMPONENT 316
ENROLLMENT-UPDATE COMPONENT 148
QUALITY-CHECK COMPONENT 328
AUDIT COMPONENT 330
DATA STORE 314
IMAGE DATA 134
OTHER DATA 136
USER PROFILE/ ACCOUNT(S) 312
PALM-FEATURE DATA 310
TRAINED MODEL(S) 318
ENROLLMENT DATABASE 150

FIG. 3

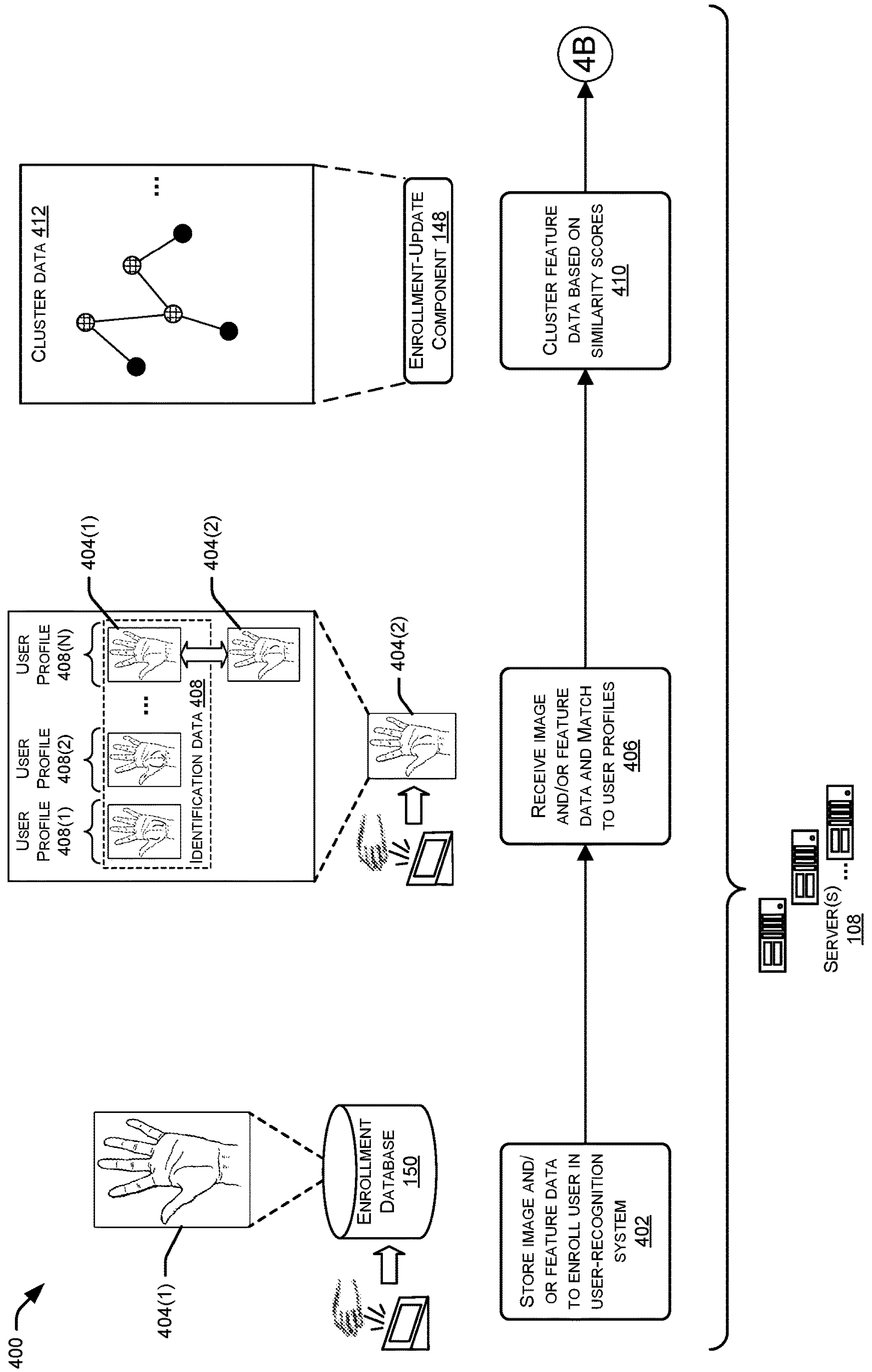

400
404(1)
Enrollment Database 150
Store image and/or feature data to enroll user in user-recognition system 402
User Profile 408(1)
User Profile 408(2)
User Profile 408(N)
404(1)
404(2)
Identification data 408
404(2)
Receive image and/or feature data and match to user profiles 406
Server(s) 108
Cluster data 412
Enrollment-Update Component 148
Cluster feature data based on similarity scores 410
4B

FIG. 4A

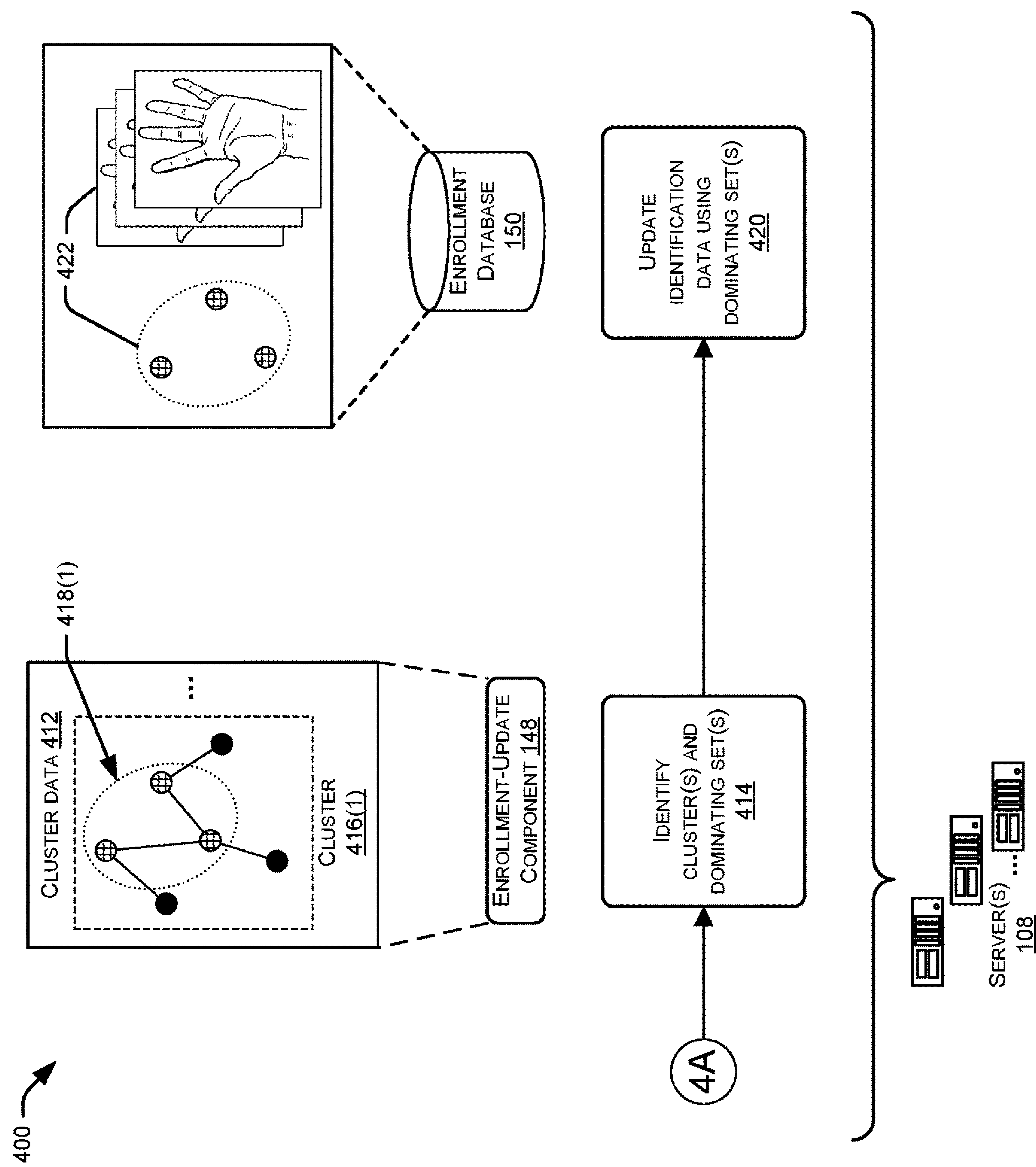

400
Cluster Data 412
418(1)
Cluster
416(1)
Enrollment-Update
Component 148
422
Enrollment
Database
150
4A
Identify
cluster(s) and
dominating set(s)
414
Update
identification
data using
dominating set(s)
420
Server(s)
108

FIG. 4B

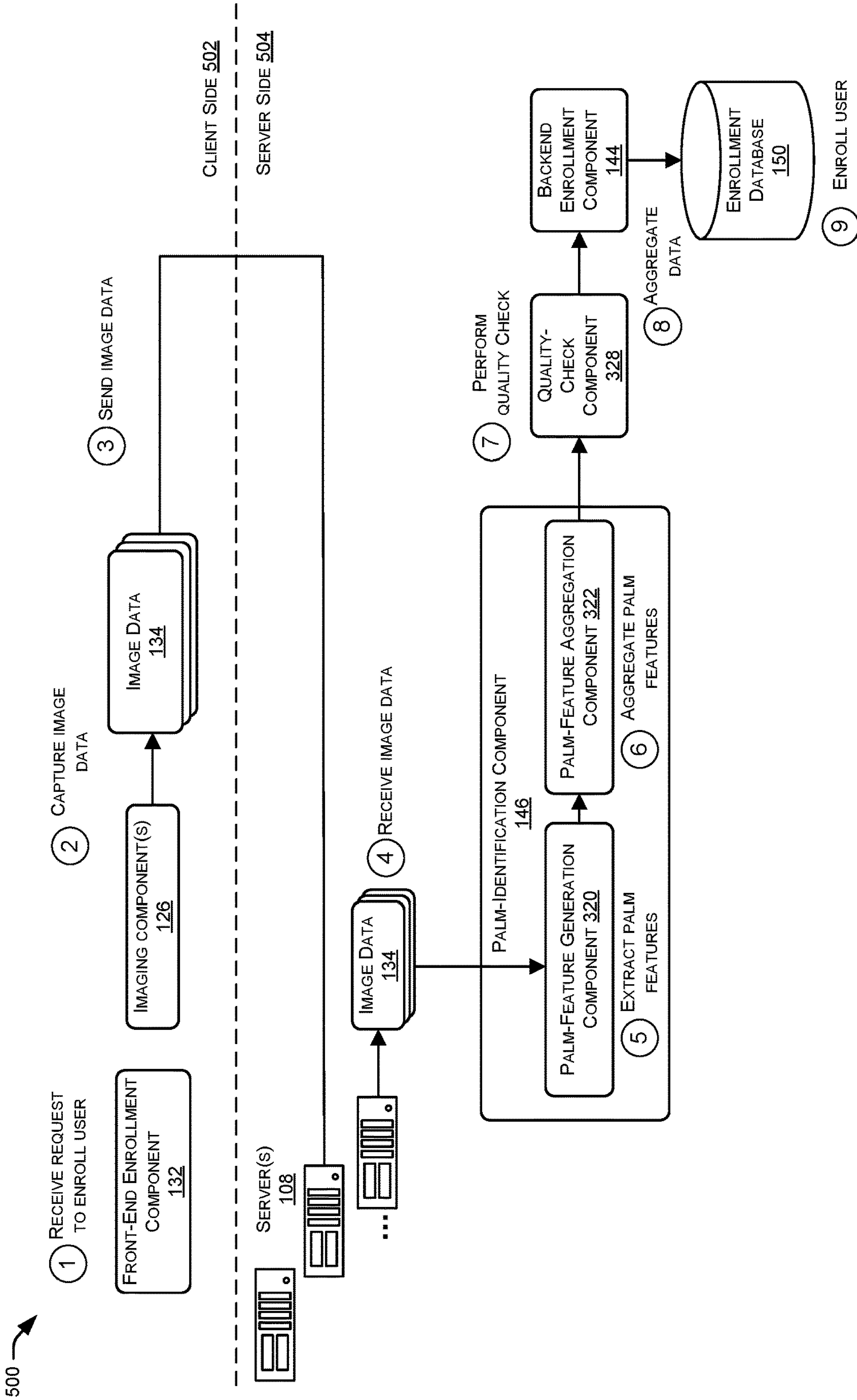

500
Client Side 502
Server Side 504
1 Receive request to enroll user
Front-End Enrollment Component 132
2 Capture image data
Imaging component(s) 126
Image Data 134
3 Send image data
Server(s) 108
...
4 Receive image data
Image Data 134
Palm-Identification Component 146
Palm-Feature Generation Component 320
5 Extract palm features
Palm-Feature Aggregation Component 322
6 Aggregate palm features
7 Perform quality check
Quality-Check Component 328
8 Aggregate data
Backend Enrollment Component 144
Enrollment Database 150
9 Enroll user

FIG. 5

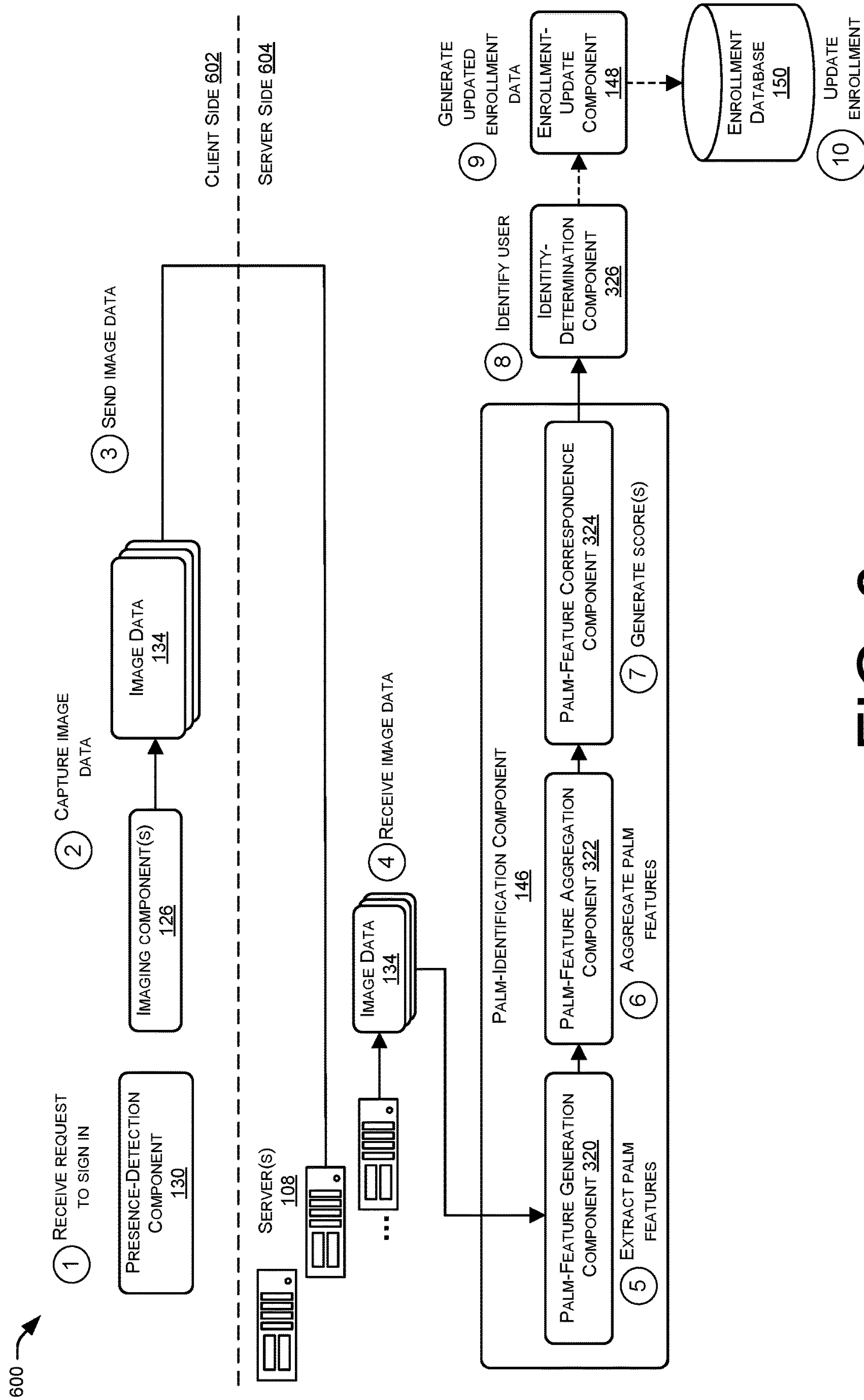
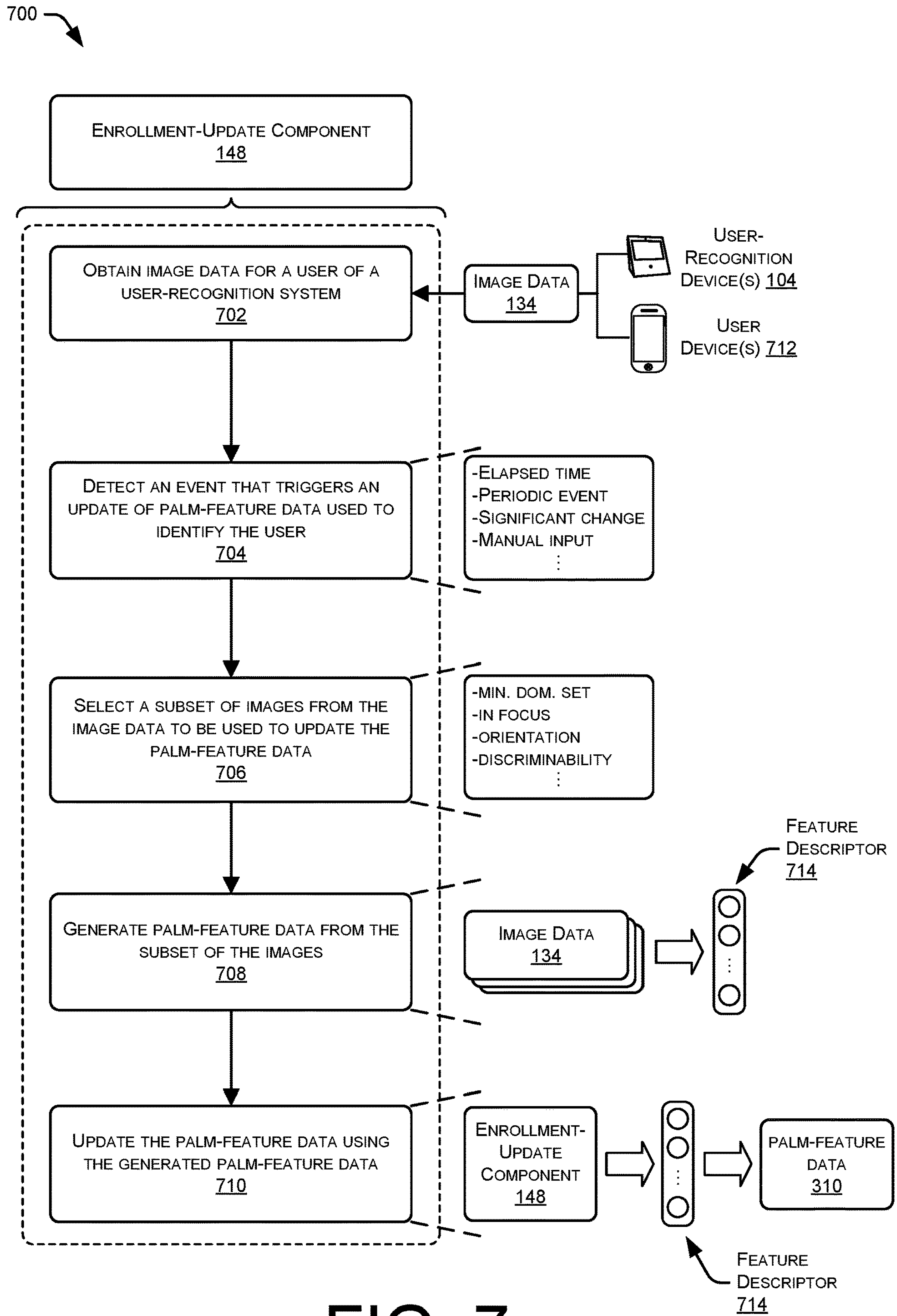

600
1 Receive request to sign in
Presence-Detection Component 130
2 Capture image data
Imaging Component(s) 126
Image Data 134
3 Send image data
Client Side 602
Server Side 604
Server(s) 108
4 Receive image data
Image Data 134
Palm-Identification Component 146
Palm-Feature Generation Component 320
5 Extract palm features
Palm-Feature Aggregation Component 322
6 Aggregate palm features
Palm-Feature Correspondence Component 324
7 Generate score(s)
8 Identify user
Identity-Determination Component 326
9 Generate updated enrollment data
Enrollment-Update Component 148
Enrollment Database 150
10 Update enrollment

FIG. 6



700
ENROLLMENT-UPDATE COMPONENT 148
OBTAIN IMAGE DATA FOR A USER OF A USER-RECOGNITION SYSTEM 702
IMAGE DATA 134
USER-RECOGNITION DEVICE(S) 104
USER DEVICE(S) 712
DETECT AN EVENT THAT TRIGGERS AN UPDATE OF PALM-FEATURE DATA USED TO IDENTIFY THE USER 704
-ELAPSED TIME
-PERIODIC EVENT
-SIGNIFICANT CHANGE
-MANUAL INPUT
SELECT A SUBSET OF IMAGES FROM THE IMAGE DATA TO BE USED TO UPDATE THE PALM-FEATURE DATA 706
-MIN. DOM. SET
-IN FOCUS
-ORIENTATION
-DISCRIMINABILITY
FEATURE DESCRIPTOR 714
GENERATE PALM-FEATURE DATA FROM THE SUBSET OF THE IMAGES 708
IMAGE DATA 134
UPDATE THE PALM-FEATURE DATA USING THE GENERATED PALM-FEATURE DATA 710
ENROLLMENT-UPDATE COMPONENT 148
PALM-FEATURE DATA 310
FEATURE DESCRIPTOR 714

FIG. 7

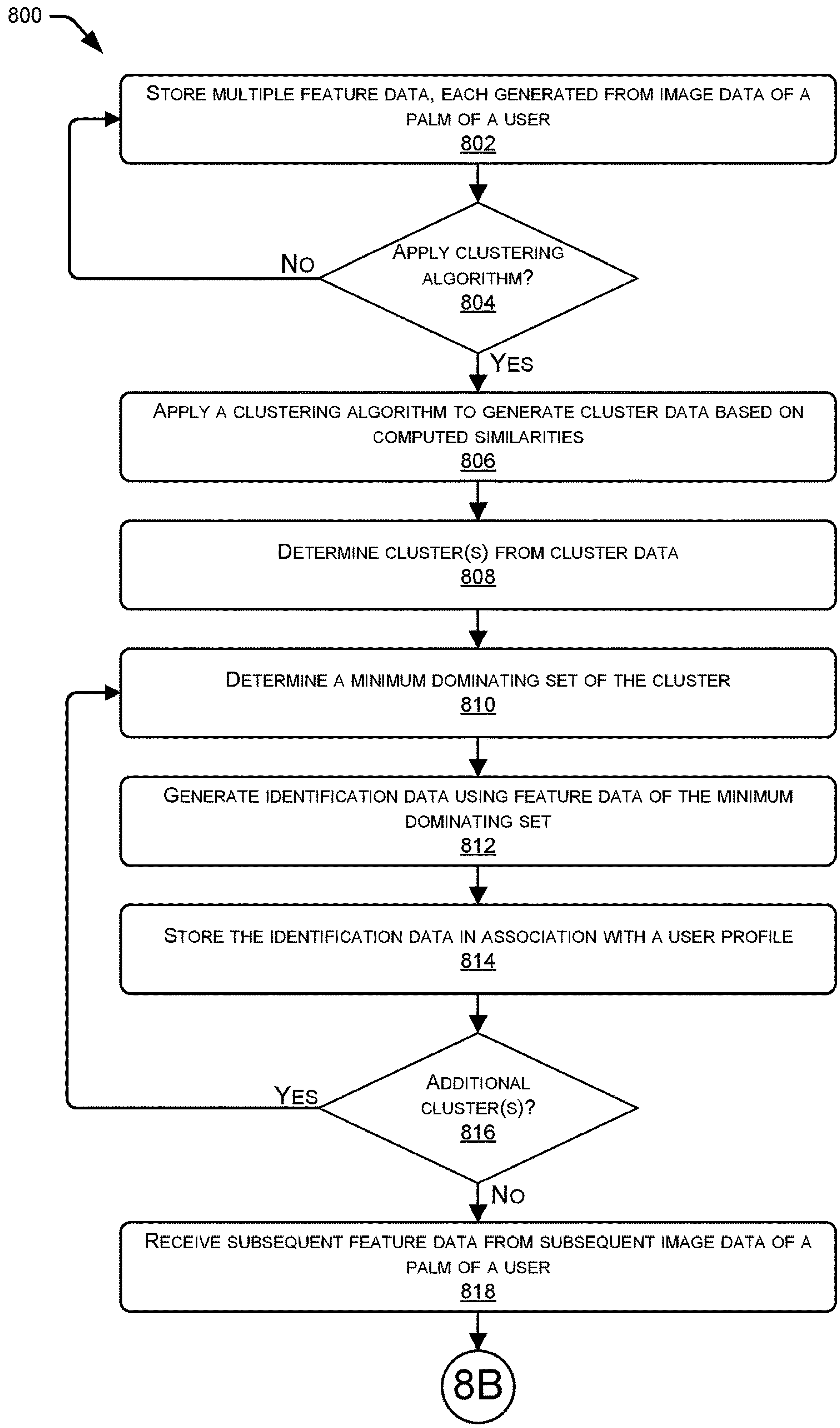

800
STORE MULTIPLE FEATURE DATA, EACH GENERATED FROM IMAGE DATA OF A PALM OF A USER
802
APPLY CLUSTERING ALGORITHM?
804
NO
YES
APPLY A CLUSTERING ALGORITHM TO GENERATE CLUSTER DATA BASED ON COMPUTED SIMILARITIES
806
DETERMINE CLUSTER(S) FROM CLUSTER DATA
808
DETERMINE A MINIMUM DOMINATING SET OF THE CLUSTER
810
GENERATE IDENTIFICATION DATA USING FEATURE DATA OF THE MINIMUM DOMINATING SET
812
STORE THE IDENTIFICATION DATA IN ASSOCIATION WITH A USER PROFILE
814
ADDITIONAL CLUSTER(S)?
816
YES
NO
RECEIVE SUBSEQUENT FEATURE DATA FROM SUBSEQUENT IMAGE DATA OF A PALM OF A USER
818
8B

FIG. 8A

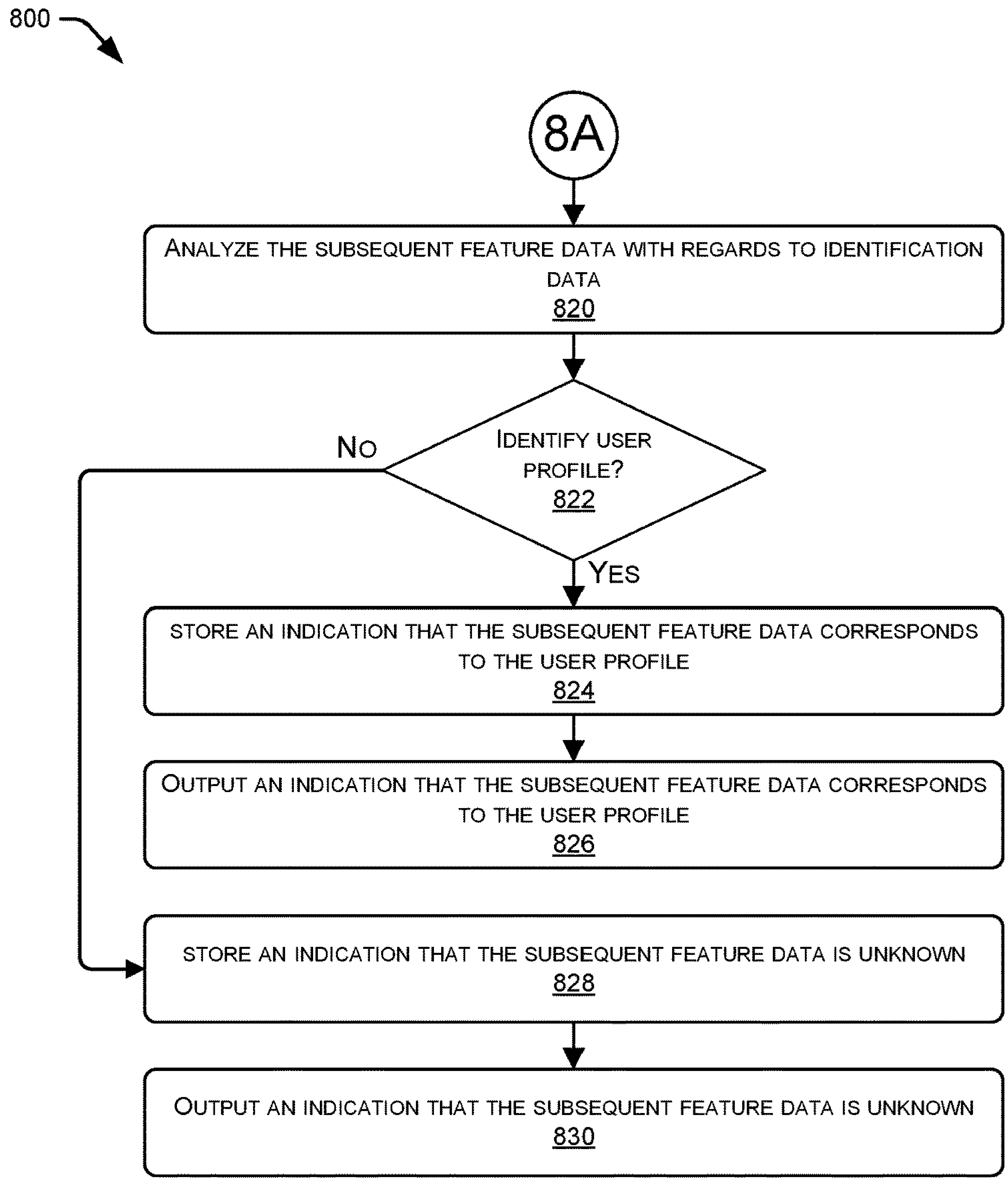

800
8A
ANALYZE THE SUBSEQUENT FEATURE DATA WITH REGARDS TO IDENTIFICATION DATA
820
IDENTIFY USER PROFILE?
822
NO
YES
STORE AN INDICATION THAT THE SUBSEQUENT FEATURE DATA CORRESPONDS TO THE USER PROFILE
824
OUTPUT AN INDICATION THAT THE SUBSEQUENT FEATURE DATA CORRESPONDS TO THE USER PROFILE
826
STORE AN INDICATION THAT THE SUBSEQUENT FEATURE DATA IS UNKNOWN
828
OUTPUT AN INDICATION THAT THE SUBSEQUENT FEATURE DATA IS UNKNOWN
830

FIG. 8B

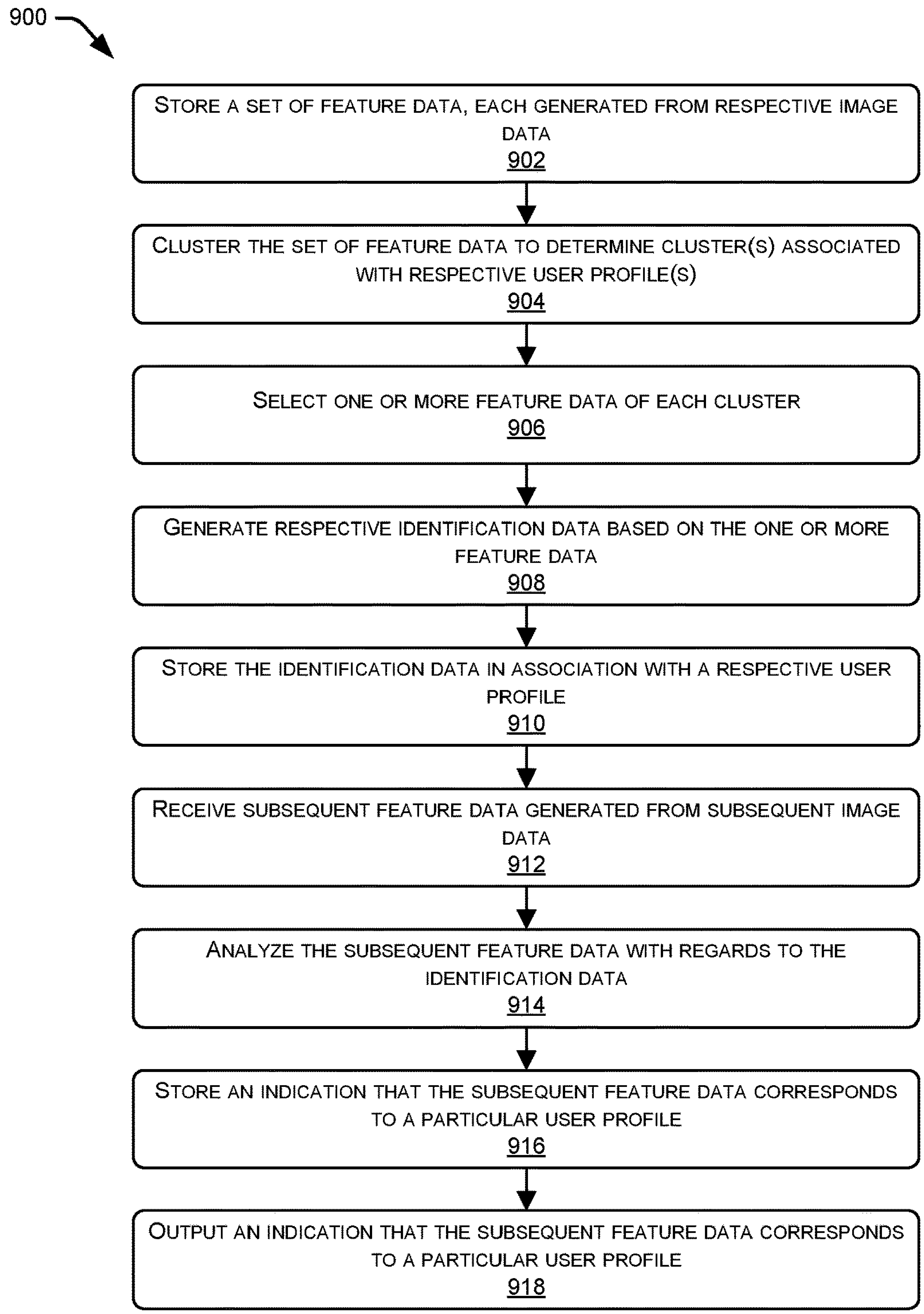

900
STORE A SET OF FEATURE DATA, EACH GENERATED FROM RESPECTIVE IMAGE DATA
902
CLUSTER THE SET OF FEATURE DATA TO DETERMINE CLUSTER(S) ASSOCIATED WITH RESPECTIVE USER PROFILE(S)
904
SELECT ONE OR MORE FEATURE DATA OF EACH CLUSTER
906
GENERATE RESPECTIVE IDENTIFICATION DATA BASED ON THE ONE OR MORE FEATURE DATA
908
STORE THE IDENTIFICATION DATA IN ASSOCIATION WITH A RESPECTIVE USER PROFILE
910
RECEIVE SUBSEQUENT FEATURE DATA GENERATED FROM SUBSEQUENT IMAGE DATA
912
ANALYZE THE SUBSEQUENT FEATURE DATA WITH REGARDS TO THE IDENTIFICATION DATA
914
STORE AN INDICATION THAT THE SUBSEQUENT FEATURE DATA CORRESPONDS TO A PARTICULAR USER PROFILE
916
OUTPUT AN INDICATION THAT THE SUBSEQUENT FEATURE DATA CORRESPONDS TO A PARTICULAR USER PROFILE
918

FIG. 9

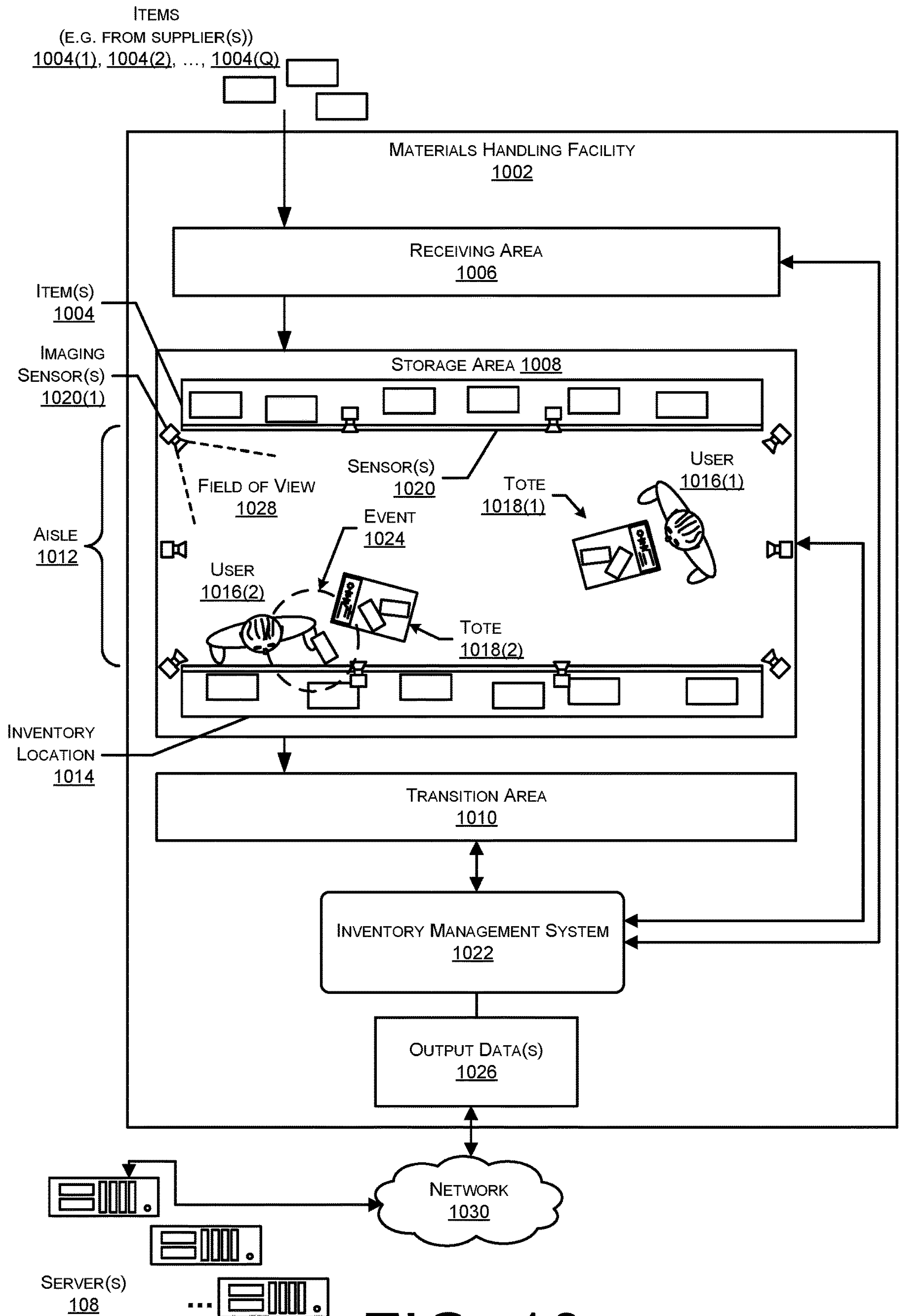

ITEMS
(E.G. FROM SUPPLIER(S))
1004(1), 1004(2), ..., 1004(Q)
MATERIALS HANDLING FACILITY
1002
RECEIVING AREA
1006
ITEM(S)
1004
IMAGING
SENSOR(S)
1020(1)
STORAGE AREA 1008
SENSOR(S)
1020
USER
1016(1)
TOTE
1018(1)
FIELD OF VIEW
1028
EVENT
1024
AISLE
1012
USER
1016(2)
TOTE
1018(2)
INVENTORY
LOCATION
1014
TRANSITION AREA
1010
INVENTORY MANAGEMENT SYSTEM
1022
OUTPUT DATA(S)
1026
NETWORK
1030
SERVER(S)
108

FIG. 10

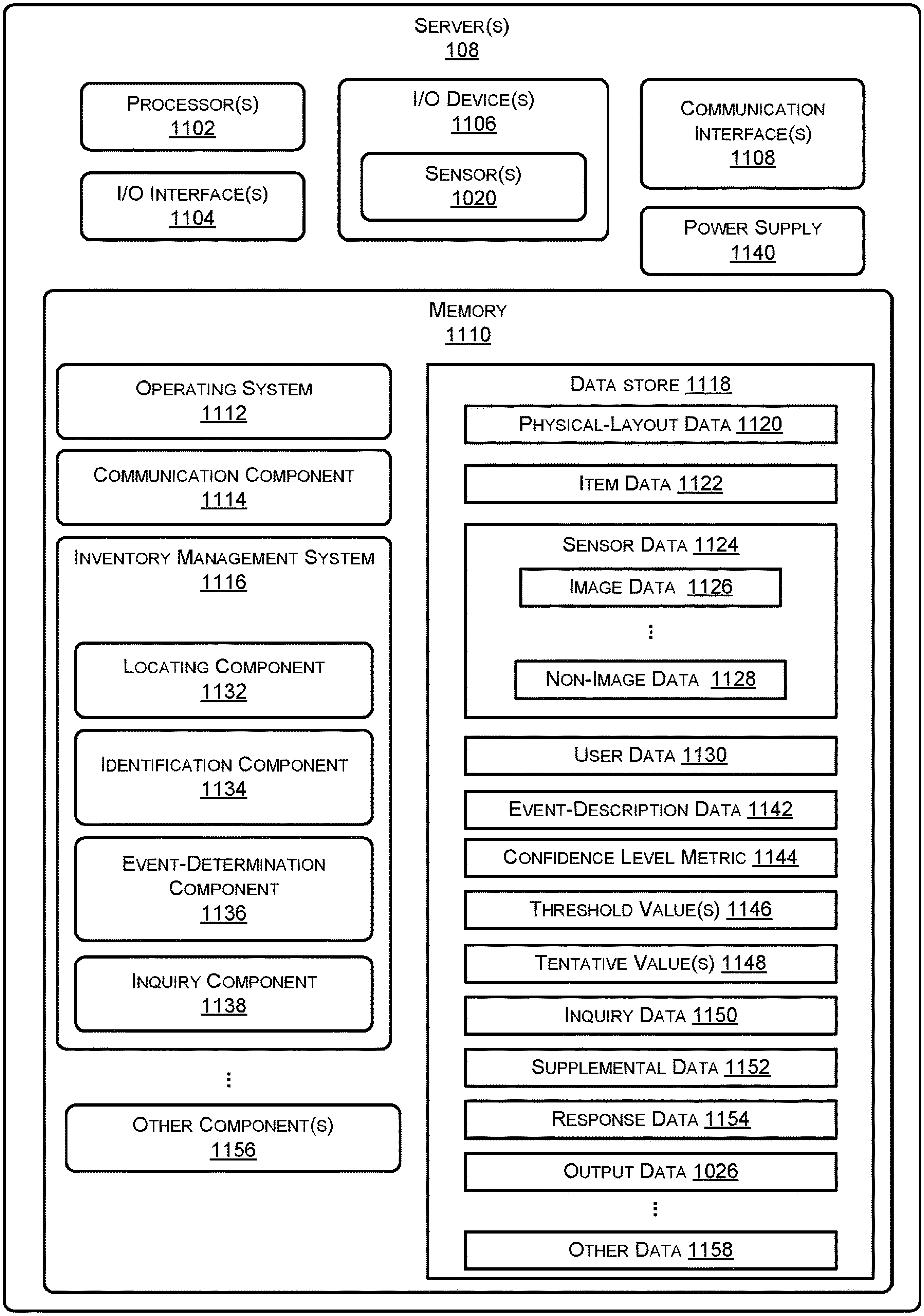

SERVER(S)
108
PROCESSOR(S)
1102
I/O INTERFACE(S)
1104
I/O DEVICE(S)
1106
SENSOR(S)
1020
COMMUNICATION INTERFACE(S)
1108
POWER SUPPLY
1140
MEMORY
1110
OPERATING SYSTEM
1112
COMMUNICATION COMPONENT
1114
INVENTORY MANAGEMENT SYSTEM
1116
LOCATING COMPONENT
1132
IDENTIFICATION COMPONENT
1134
EVENT-DETERMINATION COMPONENT
1136
INQUIRY COMPONENT
1138
OTHER COMPONENT(S)
1156
DATA STORE 1118
PHYSICAL-LAYOUT DATA 1120
ITEM DATA 1122
SENSOR DATA 1124
IMAGE DATA 1126
NON-IMAGE DATA 1128
USER DATA 1130
EVENT-DESCRIPTION DATA 1142
CONFIDENCE LEVEL METRIC 1144
THRESHOLD VALUE(S) 1146
TENTATIVE VALUE(S) 1148
INQUIRY DATA 1150
SUPPLEMENTAL DATA 1152
RESPONSE DATA 1154
OUTPUT DATA 1026
OTHER DATA 1158

FIG. 11

UPDATING IDENTIFICATION DATA IN AUTOMATED USER-IDENTIFICATION SYSTEMS

BACKGROUND

As the use of computing devices continues to proliferate, so too does the manner in which these computing devices identify and/or authenticate users. For instance, users often authenticate with a computing device by typing in a username/password combination, providing biometric data (e.g., fingerprint scan, etc.), answering one or more questions known the user, or the like. In instances of biometric information, however, the underlying information may change over time as, for instance, the user ages. Thus, it may be desirable to update identification data over time to maintain or increase a level of accuracy of an identification system.

BRIEF DESCRIPTION OF FIGURES

The detailed description is set forth with reference to the accompanying figures. In the figures, the left-most digit(s) of a reference number identifies the figure in which the reference number first appears. The use of the same reference numbers in different figures indicates similar or identical items or features.

FIG. **1** illustrates an example environment that includes a user-recognition device in communication with one or more services, which collectively form a user-recognition system in which a user may enroll in the system and later be identified via the system. In this example, the user-recognition device generates image data corresponding to a palm of the user and sends the image data to one or more servers to enroll the user in the user-recognition system. In addition, the servers may update the enrollment of the user over time to reflect potential changes in characteristics of the user's palm over time.

FIG. **2** illustrates an example process that the user-recognition system may implement for enrolling a user in the system, identifying the user, and periodically updating the identification data used for identifying the user.

FIG. **3** illustrates example components of one or more servers configured to support at least a portion of the functionality of a user-recognition system.

FIGS. **4**A-**4**B collectively illustrate an example process for enrolling a user in the user-recognition system of FIG. **1**, as well as identifying the user thereafter and updating the enrollment of the user over time.

FIG. **5** illustrates an example environment including a block diagram of one or more servers configured to support at least a portion of the functionality of a user-recognition system, as well as an example flow of data within the system for enrolling a user with the user-recognition system.

FIG. **6** illustrates an example environment including a block diagram of one or more servers configured to support at least a portion of the functionality of a user-recognition system, as well as an example flow of data within the system for identifying a user of the user-recognition system and, potentially, updating the enrollment of the user.

FIG. **7** illustrates a flow diagram of an example process for updating feature data for a user of a user-recognition system.

FIGS. **8**A-**8**B collectively illustrate a flow diagram of an example process for enrolling a user with a user-recognition system and updating this enrollment over time.

FIG. **9** illustrates another flow diagram of an example process for enrolling a user with a user-recognition system and updating this enrollment over time.

FIG. **10** is a block diagram of an example materials handling facility that includes sensors and an inventory management system configured to generate output regarding events occurring in the facility using the sensor data.

FIG. **11** illustrates a block diagram of one or more servers configured to support operation of the facility.

DETAILED DESCRIPTION

This disclosure describes systems and techniques for identifying users using biometric-recognition techniques. As described below, users may enroll with a user-recognition system that utilizes various biometric-based recognition techniques so users may be identified without having to carry or use traditional forms of identification, such as showing an ID card or accessing their personal phone. The user-recognition system may recognize, or identify, enrolled users for various purposes, such as for automating traditional checkout experiences in a materials handling facility (or "facility") by charging appropriate user accounts with purchases of items selected by enrolled users in the facility.

In one illustrative example, the systems and techniques are used to recognize or identify users within a facility, which may include, or have access to, an inventory-management system. The inventory-management system may be configured to maintain information about items, users, condition of the facility, and so forth. For example, the inventory-management system may maintain data indicative of a result of different events that occur within the facility, such as what items a particular user picks or returns, a location of the particular user, and so forth.

Operation of the inventory-management system may be supported by sensor data acquired by one or more sensors. The sensor data may include image data acquired by imaging devices such as cameras, information acquired from radio frequency tags, weight sensors, and so forth. For example, the inventory-management system may automatically identify an item removed from an inventory location as well as a user that removed the item. In response, the inventory-management system may automatically update a virtual shopping cart of the user.

Traditionally, when a user has finished their shopping session, the user would have to pay for their items by having a cashier scan their items, or by using dedicated self-checkout stands. The techniques described herein reduce friction in the traditional checkout experience by recognizing or identifying a user enrolled for use of the user-recognition system and charging a user account for that user with the cost of the items included in their virtual shopping cart. According to the techniques described herein, a user enrolled with the user-recognition system may need only provide biometric information by, for example, scanning a palm of the user at an imaging device, scanning a fingerprint of the user, looking at a camera of a user-recognition device located in the facility, speaking a predefined utterance to the device, or the like in order to be identified by the user-recognition system.

To utilize the user-recognition system, a user may request to be enrolled by interacting with a user-recognition device positioned in a facility. For example, the user may select an enroll option on a display of the user-recognition device, issue a voice or GUI-based command requesting to be enrolled, insert a user ID card into the user-recognition device, and/or simply present their hand or palm before the user-recognition device to prompt the enrollment process.

Upon requesting to be enrolled in the user-recognition system, the user-recognition device may, with permission and/or upon explicit request by the user, begin collecting various types of biometric data, and/or other data, for the user. For example, the user-recognition device may include one or more imaging sensors (e.g., a camera) that begins capturing image data (e.g., an individual image, a sequence of images, a video, etc.) of at least a portion of the user, such as a palm of the user, a face of the user, or the like. In the example of the palm, the user-recognition device may request that the user move their hand to different angles and/or orientations as the device captures the image data and may also capture image data under different lighting conditions (e.g., no flash, flash, different light polarizations, etc.), to generate image data representing the palm of the user under different environmental conditions.

In some examples, the user may already have an account registered with the inventory-management system to pay for items selected during a shopping session. In such examples, the user-recognition device may determine a user account with which the user is registered in various ways, such as by requesting that the user insert a personal ID card (e.g., driver's license), scan a barcode that may be presented on a display of a phone of the user, login with his or her login credentials, and so forth. Alternatively, the user may sign up for an account with the inventory-management system, and create a corresponding user profile, at the time of enrollment.

Once the user-recognition device has obtained the image data representing the palm or other potion of the user, the user-recognition device may utilize this data to enroll the user with the user-recognition system. In some examples, the user-recognition system may be implemented entirely on the user-recognition device, which may include the software, firmware, and/or hardware components to implement the techniques described herein. However, in some examples, the user-recognition system may be implemented according to a split architecture where the user-recognition device performs client-side enrollment and identification techniques, and more intensive and/or advanced processing may be performed using a backend, server-based implementation. For example, the user-recognition system may include one or more network-based computing devices positioned at a separate location in the facility, and/or at a remote, cloud-based location. The network-based devices may include various components for implementing the user-recognition system.

In such examples, the user-recognition device may send the image data, and/or feature data generated by the user recognition device using the image data, to the network-based devices to enroll the user for the user-recognition system. The network-based devices of the user-recognition system may perform various processing techniques on the image data and/or feature data such that the user-recognition system is able to identify the user from subsequently received image data and/or feature data.

The user-recognition system may analyze the image data to determine various features of the user. For example, the user-recognition system may extract and/or generate, based on the image data, palm-feature data representing the palm of the user. This palm-feature data may represent biometric characteristics or information that is potentially unique to the palm of the user, such as the pattern of creases in the user's palm, the pattern of veins of the user's palm, the geometry of one or more portions of the user's hand (e.g., finger sizes/shape, palm size/shape, etc.), and/or the like. The user-recognition system may utilize any type of processing techniques to generate the palm-feature data and may represent the palm of the user depicted in the image data using various types of data structures, such as feature vectors. In some examples, the user-recognition system may include one or more trained models (e.g., machine-learning models) that have been trained to receive image data of a user as input, and output feature vectors representing a palm of the user. Generally, the trained model(s) may comprise any type of models, such as machine-learning models (e.g., artificial neural networks, convolution neural networks (CNNs), classifiers, random-forest models, etc.) that may be trained to identify a palm of a user and/or one or more other portions of the user (e.g., face, etc.).

Upon obtaining the feature data that represents the palm of the user, the user-recognition system may store the feature data in an enrollment database and associate the feature data with a user profile for that specific user. In this way, when subsequent image data is received for a user at a user-recognition device, the feature data stored in the enrollment database may be compared with the feature data generated from the subsequent image data to identify a user profile for the user represented in the subsequent image data and/or audio data. As such, the feature data stored in the enrollment database may be deemed "identification data", in that it is used to compare against subsequent feature data generated based on image data (or audio data) generated at a time when the user is requesting identification and/or authentication.

In this way, the user may be enrolled for use of the user-recognition system such that, after completing subsequent shopping sessions, the user may checkout by placing his or her palm over an imaging component of a user-recognition device to allow the user-recognition system to automatically recognize the user. The user-recognition device may detect the presence of the user (e.g., detect the palm, detect a face, detect the speech utterance, detect a touch input via a touch display, etc.), and begin streaming image data and/or audio data to the backend devices of the user-recognition system. The backend devices of the user-recognition system may then utilize the trained model(s) to extract feature data and compare that feature data to stored feature data ("identification data") for user profiles of enrolled users. In addition, or in the alternative, the user may scan his or her palm for recognition upon entering the facility and, in some instances, may simply exit the facility with his or her picked items and without again scanning his or her palm. In these instances, the user may be identified upon entry and located by the system as the user moves about the facility, such that the user may "just walk out" without further interaction with associates or devices at the facility.

In some instances, the look and/or makeup of user palms may change over time (e.g., due to callouses, scars, etc.) and, thus, the palm-feature data associated with respective user profiles may need to be updated over time to allow for accurate identification. Further, in some instances the palm-feature data or other biometric-based data stored by the user-recognition system may need to be removed from the system after a threshold amount of time after generating or receiving the data to comply with regulatory requirements. Thus, the user-recognition system may again update the palm-feature data over time to allow older data to be removed while still enabling the system to identify the respective users. Furthermore, in some instances image data generated during identification attempts may be of great quality, and thus of better use in future identification attempts, than current identification data. For these and/or other reasons, the user-recognition system may update users' respective identification data over time.

In some instances, to maintain an accurate and/or current representation of the palm of the user, the user-recognition system may update the palm-feature data using image data, such as recently obtained image data, of the user. In some instances, the user-recognition system may collect and store image data for each occurrence of the user utilizing the user-recognition system, and periodically (e.g., every three months, every six months, etc.) utilize at least a portion of those images to update the palm-feature data stored in the enrollment database for the user. In some examples, the user-recognition system may update the palm-feature data upon detecting a significant change in the features of the palm of the user. By updating the palm-feature data using image data that is more recently obtained, the user-recognition system may maintain a more accurate representation of the enrolled users in order to more accurately identify enrolled users over time.

In some instances, the user-recognition system may store, for an individual user, multiple pieces of image data or palm-feature data corresponding to image data captured at different points in time. For instance, when a specific user first enrolls with the user-recognition system, the system may store, as identification data in association with a profile of the user, at least one of the image data of the user's palm and/or palm-feature data generated based on the image data. Therefore, when the user returns to a facility that utilizes the user-recognition system for identification and provides image data of the palm of the user, the palm-feature data generated using this new image data may be compared to the stored palm-feature data (i.e., the identification data) to determine when the user at the facility corresponds to the user associated with the profile. It is to be appreciated that this new palm-feature data may be compared to palm-feature data associated with multiple different user profiles for identifying the user.

Upon identifying the user by determining that the new palm-feature data corresponds to stored palm-feature data associated with a particular user profile, the user-recognition service may determine that the user at the facility corresponds to the user associated with the particular user profile. In addition to making this identification, however, the user-recognition may also store this new image data and/or the palm-feature data generated from this new image data in association with the user profile for later use in again identifying the user.

Therefore, envision that the same user again visits this facility or a different facility at still a later date. Upon the user scanning his or her palm using the user-recognition device at the facility, the user-recognition system may attempt to identify the user with reference to both the initial palm-feature data and the more-recent palm-feature data generated from the image data taken at the user's last visit to the (same or different) facility. Therefore, the user-recognition system may compare the newest palm-feature data to richer feature data, thus increasing the accuracy of the resulting recognition. Again, it is to be appreciated that the user-recognition may continue to update the identification data (e.g., palm-feature data) for each of multiple user profiles, such that the most-recently generated palm-feature data is compared to rich data across multiple different profiles.

In addition, the user-recognition system may remove older palm-feature data as the system continues to add most-recent feature data as identification data associated with a user profile. Continuing the example from above where the user initially enrolled with the system at a first time and thereafter visited the same or a different facility associated with the user-recognition system two times, the initial palm-feature data may be removed from the identification data associated with the corresponding user profile. Instead, the palm-feature data associated with the most recent two visits to the facilitie(s) may now be stored as the identification data for the user. Of course, while the above example describes removing the initially provided palm-feature data, in some instances the user-recognition system may employ weighting techniques with a sliding window to lessen the affect that older feature data has relative to newer feature data in terms of identifying users. Stated otherwise, the user-recognition may employ decay functions that cause the impact of older feature data on user recognition to decay over time.

In addition, or in the alternative, to the above, the user-recognition may periodically (e.g., nightly, weekly, etc.) update users' identification data. For instance, the user-recognition system may periodically analyze stored feature data relative to each other stored feature data to determine the similarity therebetween. The system may then use this analysis to select certain feature data to store as identification data for a particular user profile or account. Further, the system may make a similar selection for each user profile or account enrolled in the system.

To provide an example, the user-recognition system may store feature data based on image data generated at users' times of enrollment, as well as feature data based on image data captured during recognition attempts. That is, the system may store both the initial or current identification data for each user account, as well as the feature data generated from image data captured during operation of the system, such as users scanning their palms in order to be recognized by the system. At some periodicity, or in response to another trigger event, the user-recognition system may perform a process to determine whether to update identification data currently stored in association with one or more user accounts.

To begin, the user-recognition system may apply a clustering algorithm to each stored feature data. For instance, each feature data, whether generated based on image data generated at a time of enrollment or during a recognition attempt, may be considered an individual node. Then, the system may apply a clustering algorithm to generate individual clusters of nodes, with each cluster corresponding to an individual user account (and, thus, palm of an individual user). For instance, the clustering algorithm may function by comparing each "node" currently stored in the system to each other node stored in the system to determine a similarity score therebetween. For instance, first feature data may be compared to second feature data to compute a first similarity score between the first and second feature data, to third feature data to compute a second similarity score between the first and third feature data, and so forth. That is, a mathematical distance between two feature data may be computed, and each distance may be stored as a representation of a similarity between the two feature vector. Thus, each node may be compared to each other node, and each pair of nodes may be associated with a similarity score.

The user-recognition system may then compare each similarity score to a similarity-score criteria to identify those scores that satisfy the criteria (e.g., those that are greater than a threshold or otherwise indicate that they have a degree of similarity that is greater than a predefined level of similarity). Each pair of nodes having a similarity score that is greater than a threshold may be deemed connected to one another in graph data generated as a result of the clustering algorithm. Thus, as will appreciated, the clustering algorithm may output graph data that indicates multiple clusters, with each cluster being associated with a particular user profile. That is, given that each node represents a palm or other portion of a real user, most or all nodes in the system will naturally connect to other nodes that are associated with the same palm/user. Further, given that a subset of the nodes corresponding to identification data that are associated with respective user profile, each cluster itself may be deemed associated with a user profile to which the identification-data node(s) form a part of. That is, given a first node associated with a first user profile, each node coupled, directly or indirectly, to the first node may collectively define a first cluster associated with the first user profile. Similarly, given a second node associated with a second user profile, each node coupled, directly or indirectly, to the second node may collectively define a second cluster associated with the second user profile, and so forth.

After the system generates the cluster data and identifies each cluster, the system may determine whether and/or how to update the identification for each user profile associated with a cluster. In some examples, for instance, the system may identify, for each cluster, a minimum dominating set of nodes for the cluster. As is known and will be illustrated and discussed in greater detail below, a minimum dominating set of a cluster of nodes is defined as those nodes that make up a minimum number of nodes in a cluster to which each other node in the cluster directly connects. Stated otherwise, a minimum dominating set for a graph, G=(V, E) (where V is the set of nodes in the cluster and E is the set of paired nodes connected by respective edges) is a minimum subset (D) of the total nodes in the cluster (V) that every node not in D is adjacent (or directly connected) to at least one member of D. As is also known, a domination number y(G) is this number of minimum nodes (i.e., the number of nodes, D, in the dominating set).

After identifying a minimum dominating set for each cluster of the cluster data, the user-recognition system may use some or all of the feature data (i.e., nodes) of the minimum dominating set to update the identification data for the corresponding user profile. For instance, the user-recognition system may determine that a minimum dominating set for a first cluster associated with a first user profile corresponds to three nodes. The system may use these three feature data to update the identification data. For instance, the system may select one of the feature data to comprise the new identification data, may combine these three feature data to comprise the new identification data, may combine some or all of these three feature data with the previous identification data associated with the first user profile to generate the new identification data, may store each of the three feature data as the new identification data, or the like. For instance, the user-recognition may average the three feature data together and store the averaged feature data as the new identification data. In another example, the system may average these three feature data with the existing identification data and store this averaged data as the new identification data. In still other instances, the user-recognition system may perform a weighted average of some or all of the feature data in the minimum dominating set and/or the previous identification data to generate the new identification data. For instance, the system may assign a weight to each node based on a recency associated with the generation of the node, with more recent nodes being assigned a larger weight than less recent nodes. Further, in some instances the system may store each node (e.g., all three nodes) as the new identification data and may perform multiple individual recognition attempts (e.g., three recognition attempts) upon a user requesting that a recognition process be performed. Of course, while a few examples are described, it is to be appreciated that the user-recognition system may use the nodes of the minimum dominating set and/or the previous identification data to generate new identification data for the first user profile in any other manner. Further, it is to be appreciated that the user-recognition system may perform this process for updating each identification data associated with each user profile in the user-recognition system.

In some instances, a given cluster may have multiple different minimum dominating sets. For instance, a first cluster may have a dominating set made of nodes one, two, and three, along with another dominating set made of nodes one, four, and five. In these instances, the user-recognition system may determine which dominating set to use (or multiple sets) in any number of ways. For instance, the user-recognition system may identify, for each node that is not part of a particular dominating set, which edge to a node within the dominating set has a greatest similarity relative to each other edge from that node to a node in the dominating set (if the node connects to more than one node in the dominating set). For instance, the system may identify which mathematical distance between the node and a node of the dominating set is the smallest distance, representing a higher similarity. The system may perform this for each node in the dominating-set configuration to determine an overall score (e.g., a summed distance). The system may perform this process for each dominating-set configuration and may compare the computed overall scores to determine the highest similarity. For instance, the system may compare a first summed distance associated with a first dominating-set configuration to a second summed distance associated with a second dominating-set configuration to determine which distance is less (thus, representing a greater overall level of similarity). The system may then select that the dominating set for use in generating the updated identification data. Further, while one example is described, the user-recognition system may select which of multiple dominating sets to use in any other manner.

In addition, in some instances the system may determine to store, as the new identification, a number of nodes that is less than the entirety of the selected minimum dominating set. For instance, the system may determine that a number of nodes associated with the minimum dominating set is greater than a threshold number and, therefore, may determine to select a subset of these nodes. In these instances, the system may, for instance, determine, for each node, a number of other nodes that the respective node is connected and may select those nodes having the most connections. For instance, envision that a minimum dominating set of nodes for a particular cluster comprises ten nodes, which is greater than a predefined maximum number of nodes of five (for example). The system may determine which five nodes have the most individual number of connections to other nodes and may store these five nodes as the new identification data. Of course, while one criteria is discussed for selecting a sub-sample of nodes for storing as the new identification data, other criteria may additionally or alternatively be used.

Further, while the above example describes using a dominating set of a cluster to update identification data associated with a profile, it is to be appreciated that the techniques may update the identification data based on the clustering in any other manner. For instance, the techniques may update the identification data for a given cluster by averaging feature data of the cluster or feature data of any subset of the cluster (e.g., after removing outliers), using a centroid or other statistical value of the cluster, or selecting one or more nodes of the cluster in any other manner.

In addition to updating the feature data associated with user profiles over time, in some instances the user-recognition system may perform periodic or continuous audits of the system to identify potential matching errors, to correct the errors, and to retrain the system for increased future accuracy. For example, in some instances the user-recognition system may employ a first level of matching in order to identify a user upon a user entering a facility and scanning his or her palm. This first level of matching may be performed locally at the user-recognition device or at one or more network-based devices associated with the user-recognition system. Regardless, after making an initial determination of the user based on the first level of matching, the user-recognition system may employ a second, more advanced level of matching at a later time. That is, the system may use additional computing resources to cross-match the newly generated palm-feature data against even more stored palm-feature data. If the system identifies an error, the system may correct the error and use information regarding the error and the correct match to retrain one or more trained models used by the system.

To provide an example, envision that a user enters a facility and scans his or her palm. Upon generating palm-feature data associated with image data of the palm, the user-recognition system may compare this feature data to, for example, a single piece of palm-feature data associated with a first user profile, a single piece of palm-feature data associated with a second user profile, and so forth. Envision that, based on this analysis, the user-recognition determines that the user corresponds to the first user profile. Thus, the system may store an indication that any transaction that occurs within the facility by the user is to be associated with the first user profile.

At a later time, however, the system may perform a deeper analysis. For example, the user-recognition system may compare the palm-feature data of the user with multiple pieces of palm-feature data associated with the first user profile, multiple pieces of palm-feature data associated with the second user profile, and so forth. Thereafter, the user-recognition system may determine that the palm-feature data actually corresponds to the second user profile rather than the first user profile. As such, the user-recognition system may store an association between the palm feature data and the second user profile and may remove the association between the palm feature data and the first user profile. The user-recognition system may also use the information associated with the initial error and the information associated with the new match to retrain one or more trained models employed for user identification. In some instances, the system may utilize the clustering techniques described herein for identifying these errors.

In some instances, the user-recognition system may utilize different types of biometric and/or other types of information for identifying users. For example, a user may provide palm data, facial-recognition data, voice data, user ID/password data, and/or any other type of information that may be used to identify the user. To provide an example, a user may initially enroll with the user-recognition system may, for example, provide an image of a palm of the user. The system may associate the resulting feature data with an account of the user. In addition, the user may later provide additional information, such as facial-recognition data, which may also be associated with the user account. Therefore, when the user later requests that the user-recognition system identify the user, the user may scan his or her palm, provide an image of his or her face, and/or the like. The user-recognition system may then use whichever type or types of information that is provided to identify the user. Furthermore, as the user continues to engage with the user-recognition system over time, the user-recognition may continue to update identification data associated with the user as described below, potentially to include additional types of biometric data provided by the user over time.

In some instances, the user-recognition system may perform auditing processes on a periodic basis, such as nightly, weekly, or the like. In addition, or in the alternative, the user-recognition system may perform auditing processes in response to receiving user feedback, such as in response to a user indicating that he or she objects to a transaction or a match determined by the system. In still other instances, the system may perform auditing processes in response to a user being identified more or less than a threshold number of times within a certain amount of time, in response to a large transaction, in response to a transaction associated with a large number of items, in response to learning additional information regarding a user (e.g., that a user was not located at a city or state associated with a facility at which he or she was allegedly identified), or in response to occurrence of any other predefined event. In some instances, after receiving user feedback (e.g., in the form of a user indicating that he or she objects to a transaction or a match determined by the system), the user-recognition system may perform a higher level of analysis to determine whether image data associated with the transaction was misidentified. In some instances, if the system is unable to confirm with a threshold level of confidence whether it was or was not misidentified, then the user-recognition system may send the image data (potentially along with other relevant data) to a computing device associated with a human associate for analysis by the human associate. The human associate may visually compare the image data to image data associated with the user in question and, potentially other users, to determine whether the image data was misidentified.

Further, while the above example describes an example where the user-recognition system corrects an error, potentially in response to user feedback, in other instances the user-recognition system may confirm its original conclusion. For example, envision that a user states that he or she was charged for a transaction that he or she did not participate in. In response, the user-recognition system may perform a rich auditing process by comparing the palm-feature data associated with the visit in question to a large amount of palm-feature data associated with a user profile of that user and with other user profiles. Rather than identify an error, in some instances the user-recognition system may confirm the initial identification and, thus, the feedback from the user indicating he or she did not participate in the transaction may be deemed fraudulent. Again, regardless of the triggering event resulting in the audit process, in some instances the system may utilize the clustering techniques described herein for identifying these errors. That is, the system may apply a clustering algorithm to the stored feature data to identifying recognition errors that occurred during the initial recognition process. This may be used both to correct and log the error, as well as to retrain the system.

Although the techniques described herein are primarily with reference to identifying users for the purpose of identifying a user account to charge for items selected from a materials handling facility, the techniques are equally applicable to any industry in which user recognition may be helpful. For instance, the user-recognition system may be implemented for security purposes such as accessing locked locations, accessing user accounts via computing devices, accessing bank accounts, and so forth. Further, while certain types of machine-learning models and algorithms are discussed herein, the techniques may be employed using other types of technologies and are generally scalable to different computer-based implementations.

The following description describes use of the techniques within a materials handling facility. The facility described herein may include, but is not limited to, warehouses, distribution centers, cross-docking facilities, order fulfillment facilities, packaging facilities, shipping facilities, rental facilities, libraries, retail stores, wholesale stores, museums, or other facilities or combinations of facilities for performing one or more functions of materials (inventory) handling. In other implementations, the techniques described herein may be implemented in other facilities or situations. For instance, the described techniques for utilizing biometric data for identifying users upon their explicit request, as well as the clustering techniques for generating and updating identification data within these systems, may be utilized in an array of environments for an array of purposes. For instance, these techniques may be utilized for identifying users upon entry to an environment (e.g., upon entry to a secure area of an environment), identifying users requesting to utilize equipment or other physical apparatuses, identifying users at kiosks or other locations, and/or any other type of environment where users may request to be identified and/or authenticated.

Certain implementations and embodiments of the disclosure will now be described more fully below with reference to the accompanying figures, in which various aspects are shown. However, the various aspects may be implemented in many different forms and should not be construed as limited to the implementations set forth herein. The disclosure encompasses variations of the embodiments, as described herein. Like numbers refer to like elements throughout.

FIG. **1** illustrates an example environment **100** of a materials handling facility **102** that includes a user-recognition device **104** to determine that a user would like to enroll for use of a user-recognition system. In this example, the user-recognition device **104** generates image data depicting a palm of a user **106** and sends the image data to one or more backend servers **108** to be used to enroll the user for use of the user-recognition system. Generally, the user-recognition system may include the user-recognition device **104** and/or the server(s) **108**.

In some instances, some or all of the user-recognition system resides remotely from the materials handling facility **102**, while in other instances some or all of the user-recognition system resides within or proximate to the materials handling facility **102**. As FIG. **1** depicts, the user **106** may have engaged in, or be about to engage in, a shopping session in the materials handling facility **102**. For instance, the user **106** may have selected an item **110** from an inventory location **112** (e.g., shelf, aisle, etc.) and placed the item **110** in a tote **114** (e.g., shopping cart). The inventory location **112** may house one or more different types of items **110** and the user **106** may pick (i.e., take) one of these items **110**.

As illustrated, the materials handling facility **102** (or "facility") may include one or more sensors, such as the illustrated imaging sensors **116**, and/or an array of other sensors located on or near the inventory location(s) **112**. In this example, the imaging sensor(s) **116** are configured to capture video data within the facility **102** for use in determining results associated with events, such as the picking of the item **110** by the user **106**. While FIG. **1** illustrates various example sensors, the sensors in the facility **102** may comprise any other type of sensor, such as weight sensors (e.g., load cells), microphones, and/or the like, as described in detail below. As described in more detail with respect to FIGS. **10** and **11**, the facility **102** may be monitored and/or otherwise associated with an inventory-management system configured to determine events in the facility **102** associated with the user **106**, such as taking items **110** that the user **106** would like to purchase. The inventory-management system may track the items **110** selected by the user **106** and maintain a virtual shopping cart which includes all of the items **110** taken by the user **106**. Thus, when a user **106** would like to leave the facility **102** with the items **110** they have taken, the inventory-management system may charge a user account associated with the user **106** for the cost of the items **110** that were taken.

As shown in FIG. **1**, the user **106** may approach a checkout location **118** associated with the user-recognition device **104**. The user **106** may determine that they would like to enroll for use of a user-recognition system in order to checkout of the facility **102** and pay for their item(s) **110**. Alternatively, or additionally, the user may interact with the user-recognition device **104** upon entering the facility **102**. In either instance, the user **106** may determine that they would like the user-recognition system to collect data that is usable to identify an account or profile of the user **106**. This data may be utilized by the user-recognition system such that, once enrolled, the user **106** need only scan his or her palm to be identified by the user-recognition system in order to charge their user account with the purchase of their item(s) **110**.

As illustrated, the user-recognition device **104** may comprise one or more processors **120** configured to power components of the device **104** and may further include memory **122** which stores components that are at least partially executable by the processor(s) **120**, as well as other data. For example, the memory **122** may include a presence-detection component **130** to detect the presence of a user **106** and a front-end enrollment component **132** configured to perform various operations for enrolling the user **106** for use of the user-recognition system. The front-end enrollment component **132** may receive a request to enroll the user **106** for use of the user-recognition system. The request may comprise various types of input, such as a selection made via an I/O interface **128** (e.g., touch screen, mouse, keyboard, etc.) of a user interface element presented on a display for starting an enrollment process. Additionally, the front-end enrollment component **132** may detect a speech utterance from the user **106** indicating a request to enroll (e.g., "please enroll me," "I would like to check out," etc.). Another request example may include the user **106** sliding a user ID card into an I/O interface **128**, such as a credit card, driver's license, etc. However, any type of input may be detected as a request by the front-end enrollment component **132**.

In some examples, the presence-detection component **130** may be executable by the processor(s) **120** to detect a trigger indicating presence of the user **106**. The trigger detected by the presence-detection component **130** may comprise one or more types of input. For instance, the presence-detection component **130** may include logic to detect, using one or more imaging components **126**, a palm of the user **106** over or proximate to the user-recognition device **104**. Other examples of triggers detected by the presence-detection component **130** that may indicate the presence of the user

106 may include receiving touch input (or other input, such as a mouse click) via one or more I/O interfaces **128** of the user-recognition device **104**. However, any type of input may be detected as a trigger by the presence-detection component **130** at **144**. In some examples, the trigger detection at **144** may not be performed, or may be included in or the same as receiving the request to enroll.

After receiving the request to enroll from the user **106**, the front-end enrollment component **132** may, begin generating image data **134** using one or more imaging component(s) **126** (e.g., cameras). For instance, the front-end enrollment component **132** may utilize the imaging component(s) **126** to obtain image data **134** such as an image or picture, a sequence of consecutive images, and/or video data. The image data **134** may represent the palm of the user **106** and may be used to identify creases in the palm, veins in the palm, geometric information regarding the palm and other parts of the hand or the user **106** and/or the like. Once the front-end enrollment component **132** has obtained the image data **134** representing the palm or other portion of the user **106**, the user-recognition device **104** may send (e.g., upload, stream, etc.) the image data **134** to the servers **108** over one or more networks **138** using one or more communication interfaces **124**.

The network(s) **138** may include private networks such as an institutional or personal intranet, public networks such as the Internet, or a combination thereof. The network(s) **138** may utilize wired technologies (e.g., wires, fiber optic cable, and so forth), wireless technologies (e.g., radio frequency, infrared, acoustic, optical, and so forth), or other connection technologies. The network(s) **138** is representative of any type of communication network, including one or more of data networks or voice networks. The network(s) **138** may be implemented using wired infrastructure (e.g., copper cable, fiber optic cable, and so forth), a wireless infrastructure (e.g., cellular, microwave, satellite, etc.), or other connection technologies.

The communication interface(s) **124** may include devices configured to couple to personal area networks (PANs), wired and wireless local area networks (LANs), wired and wireless wide area networks (WANs), and so forth. For example, the communication interfaces **124** may include devices compatible with Ethernet, Wi-Fi™, and so forth. In some examples, the communication interface(s) **124** may encode the image data **134** and/or other data **136** generated by the user-recognition device **104** prior to sending over the network(s) **138** according to the type of protocol or standard being used.

As illustrated, the servers **108** may comprise one or more processors **140** and memory **142**, which may store a backend-enrollment component **144**, a palm-identification component **146**, an enrollment-update component **148**, and an enrollment database **150**. While certain functionality of these components are introduced here, further detail regarding these components is described with reference to FIG. **3**.

Upon receiving the image data **134** from the user-recognition device **104**, one or more components of the back-end servers **108**, such as the backend-enrollment component **144** or the palm-identification component **146**, may generate feature data using the image data. This feature data may be in a vector form and may represent characteristics about the user's palm that may be used to differentiate the palm from other user palms. It is to be appreciated that while the servers **108** are described as generating the feature data, in other instances the user-recognition device **104** may be configured to generate the feature data and may send the feature data, in addition to or rather than the image data **134**, to the servers.

One or more components of the servers **108**, such as the backend-enrollment component **144** or the palm-identification component **146**, may store the feature data as identification data in the enrollment database **150** in association with a user profile of the user **106**. That is, this palm-feature data (or "identification data") is stored such that it may be compared to feature data generated from subsequent image data for later identification of the user **106** at the facility **102** or other facilities that are associated with the user-recognition system.

After the user has enrolled in the user-recognition system, the imaging components **126** may receive additional image data of the palm of the user **106** and/or of palms of users of the system, such as at a time when the user **106** or other users return to the facility **102** at a later date. After the servers **108** receive the additional image data from the user-recognition device **104**, the palm-identification component **146** or other components(s) of the servers **108** may generate additional feature data based on the additional image data. At this point, one or more components of the servers **108**, such as the palm-identification component **146**, may compare the additional feature data to feature data stored in respective user profiles for the purpose of identifying the user associated with the additional image data. For example, the user-recognition system may compare the additional feature data generated with the identification data stored in association with the user profile of the user **106** to determine that the additional image data corresponds to the user **106**. In response to determining that the additional image data corresponds to the user profile associated with the user **106**, the servers **108** may store this indication and output a notification that the user has been recognized. For instance, the servers **108** may cause the user-recognition device **104** to output a visual and/or audible indication regarding the successful recognition and/or may perform additional actions, such as charge a payment instrument associated with the user profile for any items acquired from the facility **102**. In addition, the servers **108** may store the additional feature data in association with the profile of the user **106** in the enrollment database **150**. This additional feature data may be used to update the identification data associated with the user **106**, as described below.

As introduced above, the user-recognition system may also update the identification data associated with the user **106**, and other users, as stored in the enrollment database **150**. The enrollment-update component **148**, for instance, may be configured to periodically (e.g., nightly, weekly, etc.) update users' identification data in the enrollment database **150**. For instance, the enrollment-update component **148** may periodically analyze stored feature data relative to each other stored feature data to determine the similarity therebetween. The enrollment-update component **148** may then use this analysis to select certain feature data to store as identification data for a particular user profile or account in the enrollment database **150**. Further, the enrollment-update component **148** may make a similar selection for each user profile or account enrolled in the system.

In order to update the identification data associated with multiple user accounts, the enrollment-update component **148** may apply a clustering algorithm to each stored feature data to generate cluster data **152**. Within the cluster data **154**, each illustrated node may correspond to individual feature data, whether generated based on image data generated at a time of enrollment or during a recognition attempt. Stated otherwise, each node represents feature data associated with a time at which the user-recognition device **104** generated image data corresponding to a palm of a user of the user-recognition system.

The clustering algorithm applied by the enrollment-update component **148** may function by comparing each "node" currently stored in the enrollment database **150** to each other node stored in the enrollment database **150** to determine a similarity score therebetween. For instance, first feature data may be compared to second feature data to compute a first similarity score between the first and second feature data, to third feature data to compute a second similarity score between the first and third feature data, and so forth. That is, a mathematical distance between two feature data may be computed, and each distance may be stored as a representation of a similarity between the two feature vector. Thus, each node may be compared to each other node, and each pair of nodes may be associated with a similarity score.

The enrollment-update component **148** may then compare each similarity score to a similarity-score criteria to identify those scores that satisfy the criteria (e.g., those that are greater than a threshold or otherwise indicate that they have a degree of similarity that is greater than a predefined level of similarity). Each pair of nodes having a similarity score that is greater than a threshold may be deemed connected to one another in graph data generated as a result of the clustering algorithm. FIG. **1**, for instance, illustrates that certain nodes may be connected, via an edge, to one or more other nodes when the similarity therebetween is greater than a similarity-score threshold.

After generating the cluster data **152**, the enrollment-update component **148** may analyze the cluster data **152** to identify clusters within the data **152**. FIG. **1**, for instance, illustrates that the enrollment-update component **148** has identified a first cluster **154**(**1**) consisting of six nodes, a second cluster **154**(**2**) consisting of five nodes, and a N^{th} cluster **154**(N) consisting of seven nodes. As illustrated, each respective cluster is generally independent of each other cluster, given that it is unlikely that a node associated with a palm of one user will be deemed to be sufficiently similar to a node associated with a palm of another user so as to warrant an edge connection therebetween.

After identifying the different clusters **154**, the enrollment-update component **148** may use one or more of the nodes (i.e., feature data) to update one or more identification data stored in the enrollment database **150**. For instance, the enrollment-update component **148** may use one or more nodes from the first cluster **154**(**1**) to update identification associated with a first user profile (e.g., associated with the illustrated user **106**), one or more nodes from the second cluster **154**(**2**) to update identification data associated with a second user profile, and so forth.

To update this identification data, the enrollment-update component **148** may identify a dominating set, such a minimum dominating set, from each cluster **154**. A minimum dominating set of a cluster of nodes is defined as those nodes that make up a minimum number of nodes in a cluster to which each other node in the cluster directly connects. Stated otherwise, a minimum dominating set for a graph, G=(V, E) (where V is the set of nodes in the cluster and E is the set of paired nodes connected by respective edges) is a minimum subset (D) of the total nodes in the cluster (V) that every node not in D is adjacent (or directly connected) to at least one member of D. As is also known, a domination number y(G) is this number of minimum nodes (i.e., the number of nodes, D, in the dominating set). In the illustrated example, for instance, the enrollment-update component **148** may identify a minimum dominating set **156**(**1**) (consisting of three nodes) for the first cluster **154**(**1**), a minimum dominating set **156**(**2**) (consisting of one node) for the second cluster **154**(**2**), and a minimum dominating set **156** (N) (consisting of two nodes) for the N^{th} cluster **154**(N).

After identifying a minimum dominating set **156** for each cluster **154** of the cluster data **152**, the enrollment-update component **148** may use some or all of the feature data (i.e., nodes) of the respective minimum dominating set to update the respective identification data for the corresponding user profile. For instance, the enrollment-update component **148** may use the three nodes from the first dominating set **156**(**1**) to generate new identification (ID) data **158**(**1**) associated with the first user profile, the single node from the second dominating set **156**(**2**) to generate new identification data **158**(**2**) associated with the second user profile, and the new nodes associated with the N^{th} dominating set **156**(N) to generate new identification data **158**(N) associated with the N^{th} user profile. Thereafter, subsequent palm-feature data generated from subsequent image data may be compared to the updated identification data **158**(**1**)-(N) to determine which user profile corresponds to the subsequent feature data.

The enrollment-update component **148** may use the feature data associated with the dominating sets **156** to update identification data **158** in a number of ways. For instance, the enrollment-update component **148** may select one of the feature data to comprise the new identification data, may combine these feature data from the dominating to comprise the new identification data, may combine some or all of these feature data with the previous identification data associated with the respective user profile to generate the new identification data, or the like. For instance, the enrollment-update component **148** may average the three nodes from the dominating set **156**(**1**) and store this averaged feature data as the new identification data **158**(**1**) in association with the first user profile. In another example, the enrollment-update component **148** may average these three feature data with the existing identification data and store this averaged data as the new identification data **158**(**1**). In still other instances, the enrollment-update component **148** may perform a weighted average of some or all of the feature data in the minimum dominating set and/or the previous identification data to generate the new identification data **158**(**1**). For instance, the enrollment-update component **148** may assign a weight to each node based on a recency associated with the generation of the node, with more recent nodes being assigned a larger weight than less recent nodes. In still other instances, the enrollment-update component **148** may store each node as the new identification data. Of course, while a few examples are described, it is to be appreciated that the enrollment-update component **148** may use the nodes of the minimum dominating set and/or the previous identification data to generate new identification data **158**(**1**) for the first user profile and other user profiles in any other manner.

While not illustrated in FIG. **1**, in some instances, a given cluster **154** may have multiple different minimum dominating sets. For instance, a particular cluster **154** may have a dominating set made of nodes one, two, and three, along with another dominating set made of nodes one, four, and five. In these instances, the enrollment-update component **148** may determine which dominating set to use (or multiple sets) in any number of ways. For instance, the enrollment-update component **148** may identify, for each node that is not part of a particular dominating set, which edge to anode within the dominating set has a greatest similarity relative to each other edge from that node to a node in the dominating set (if the node connects to more than one node in the dominating set). For instance, the enrollment-update component **148** may identify which mathematical distance between the node and a node of the dominating set is the smallest distance, representing a higher similarity. The system may perform this for each node in the dominating-set configuration to determine an overall score (e.g., a summed distance). The enrollment-update component **148** may perform this process for each dominating-set configuration and may compare the computed overall scores to determine the highest similarity. For instance, the system may compare a first summed distance associated with a first dominating-set configuration to a second summed distance associated with a second dominating-set configuration to determine which distance is less (thus, representing a greater overall level of similarity). The enrollment-update component **148** may then select the dominating set for use in generating the updated identification data. Further, while one example is described, the enrollment-update component **148** may select which of multiple dominating sets to use in any other manner.

Further, in some instances the cluster data **152** may serve to connect one or more nodes that previously were not recognized by the system during the recognition process. For instance, envision that one of the nodes in the cluster **154(1)** represents feature data generated from image data of a user palm during a failed recognition attempt. The process of generating the cluster data **152**, however, may serve to associate this node with the cluster **154(1)** and, thus, to the corresponding user account or profile. Thus, in addition to being used to update the identification data for individual user profiles, the clustering process may also be used to associate previously unrecognized nodes with user profiles, which may not only associate that node with the cluster/profile but may also increase the accuracy of the system. Further, in some instances when a previous unidentified node is thereafter associated with a particular cluster during the clustering process, this new association may serve as a trigger or input to cause new identification to be generated for this particular cluster. That is, given that the node was not successfully identified during the recognition process, the later associating the node with the cluster may indicate that the identification data for that particular cluster should be updated to avoid subsequent recognition failures.

FIG. **2** illustrates an example process **200** that the user-recognition system may implement for enrolling a user in the system, identifying the user, and periodically updating the identification data used for identifying the user. In some instances, the operations of the process **200** may be performed by the servers **108** in communication with the user-recognition device **104**.

At an operation **202**, the servers **108** receive a request to enroll a user in a user-recognition system. For instance, the user may operate the user-recognition device, their mobile device, or another electronic device to submit an enrollment request. At an operation **204**, the servers **108** receive image data, such as image data of a palm or other portion of the user. At an operation **206**, the servers **108** generate feature data using the image data. As described herein, the feature data may comprise a feature vector representing the palm of the user, such as a 128-dimension feature vector representing the palm of the user. Further, while the process **200** describes the servers **108** receiving the image data and generating the feature data therefrom, in some instances the user-recognition device may generate the feature data from the image data and provide the feature data to the servers **108**.

At an operation **208**, the servers **108** may store the feature data as identification data in the enrollment database **150**. That is, this feature data may be stored in association with a user account or profile of the user and may be used for comparing subsequently received/generated feature data for identifying the user at the user-recognition system as part of subsequent recognition attempts. At an operation **210**, for instance, the servers **108** (or the user-recognition device **104**) receives additional image data and, at an operation **212**, generates and stores additional feature data based on the additional image data. Again, in some instances, the user-recognition device **104** may generate the additional feature data from the additional image data and provide the additional feature data to the servers **108**.

In either instance, in addition to storing the additional feature data, the servers **108** may compare the additional feature data to identification feature to attempt to identify a user account or profile that corresponds to the user that is associated with the additional feature data. For instance, the servers **108** may compare the additional feature data to the identification data stored at the operation **208**, as well as to identification data associated with other user accounts or profiles. Upon identifying a match, the servers **108** may output an indication of the match and/or perform another action, such as associate a transaction with the corresponding user profile.

Further, an operation **216** represents the servers **108** periodically performing clustering of feature data stored at the servers **108**. As described above, this operation may comprise applying a clustering algorithm to feature data that is stored as identification data and feature data received during recognition attempts. Further, in some instances the clustering algorithm compares each individual feature data with each other individual feature data to determine a similarity therebetween. The clustering algorithm may thereafter determine the similarity scores that meet one or more similarity criteria (indicating a relatively high level of similarity) and may store an indication of a connection between these two feature data.

An operation **218** represents identifying clusters within the resulting cluster and identifying a respective dominating set within each cluster. For instance, the servers **108** may identify "N" number of clusters and, for each cluster, may identify a minimum dominating set of nodes (or feature data) from the cluster. If a cluster has multiple minimum dominating sets, the servers **108** may select one or more of the minimum dominating sets using the techniques described above. Finally, an operation **220** represents storing feature associated with the dominating sets as identification data in the enrollment database **150**. As described above, this operation may comprise replacing each of the previous identification data with the new feature data indicated in the dominating sets, merging the new feature data with the previous identification data, or the like.

FIG. **3** illustrates example components of one or more servers **108** configured to support at least a portion of the functionality of a user-recognition system. In some examples, the user-recognition system described herein may be supported entirely, or at least partially, by the user-recognition device **104** in conjunction with the servers **108**. The server(s) **108** may be physically present at the facility **102**, may be at a remote location accessible by the network **138**, or a combination of both. The server(s) **108** do not require end-user knowledge of the physical location and configuration of the system that delivers the services. Common expressions associated with the server(s) **108** may include "on-demand computing," "software as a service (SaaS)," "cloud services," "data centers," and so forth. Services provided by the server(s) **108** may be distributed across one or more physical or virtual devices.

The server(s) **108** may include one or more hardware processors **140** (processors) configured to execute one or more stored instructions. The processors **140** may comprise one or more cores. The server(s) **108** may include one or more input/output (I/O) interface(s) **302** to allow the processor **140** or other portions of the server(s) **108** to communicate with other devices. The I/O interfaces **302** may comprise Inter-Integrated Circuit (I2C), Serial Peripheral Interface bus (SPI), Universal Serial Bus (USB) as promulgated by the USB Implementers Forum, RS-232, and so forth.

The server(s) **108** may also include one or more communication interfaces **304**. The communication interfaces **304** are configured to provide communications between the server(s) **108** and other devices, such as the user-recognition device **104**, the interface devices, routers, and so forth. The communication interfaces **304** may include devices configured to couple to personal area networks (PANs), wired and wireless local area networks (LANs), wired and wireless wide area networks (WANs), and so forth. For example, the communication interfaces **308** may include devices compatible with Ethernet, Wi-Fi™, and so forth.

The server(s) **108** may also include one or more busses or other internal communications hardware or software that allow for the transfer of data between the various modules and components of the server(s) **108**.

As shown in FIG. **3**, the server(s) **108** includes one or more memories **142**. The memory **142** comprises one or more computer-readable storage media (CRSM). The CRSM may be any one or more of an electronic storage medium, a magnetic storage medium, an optical storage medium, a quantum storage medium, a mechanical computer storage medium, and so forth. The memory **142** provides storage of computer-readable instructions, data structures, program modules, and other data for the operation of the server(s) **108**. A few example functional modules are shown stored in the memory **142**, although the same functionality may alternatively be implemented in hardware, firmware, or as a system on a chip (SOC).

The memory **142** may include at least one operating system (OS) **306**. The OS **306** is configured to manage hardware resource devices such as the I/O interfaces **302**, I/O devices, the communication interfaces **304**, and provide various services to applications or modules executing on the processors **140**. The OS **306** may implement a variant of the FreeBSD™ operating system as promulgated by the FreeBSD Project; other UNIX™ or UNIX-like variants; a variation of the Linux™ operating system as promulgated by Linus Torvalds; the Windows® Server operating system from Microsoft Corporation of Redmond, Wash., USA; and so forth.

One or more of the following components may also be stored in the memory **142**. These modules may be executed as foreground applications, background tasks, daemons, and so forth.

A communication component **308** may be configured to establish communications with one or more of the imaging sensors **116**, the user-recognition devices **104**, other server(s) **108**, or other devices. The communications may be authenticated, encrypted, and so forth.

A backend-enrollment component **144** may be configured to perform various operations for enrolling a user **106** for use of the user-recognition system. For instance, the backend-enrollment component **144** may perform various operations, and/or cause other components to perform various operations, to enroll users **106** in the user-recognition system. In some instance, the backend-enrollment component **144** may at least partly control a palm-identification component **146** that performs operations for analyzing image data **134** depicting a palm or other portion of the user **106**. In some examples, the backend-enrollment component **144** may cause the palm-identification component **146** to analyze the image data **134** and extract features which represent a palm of the user **106**, such as palm-feature data **310**.

After obtaining, determining, and/or generating the palm-feature data **310**, the backend-enrollment component **144** may enroll the user **106** in an enrollment database **150** which indicates that the user **106** is enrolled for use of the user-recognition system. In some examples, the backend-enrollment component **144** may associate, or map, the various data to a user profile/account **312** that is associated with the user **106**. For example, the backend-enrollment component **144** may map, for each enrolled user **106**, respective palm-feature data **310** to corresponding user profiles **312** in the enrollment database **150**. Thus, the enrollment database **150** may store indications of user profiles **312**, as well as the data for users **106** associated with each of the user profiles **312**. When a user **106** is enrolled for use of the user-recognition system, the backend-enrollment component **144** may map, or store an association, between the user's **106** palm-feature data **310** with the user profile **312** for that user **106**. Further, the user profile **312** may include various information for the user **106**, such as payment information to perform transactions for items **110** selected by the user **106** from the facility **102**. The various types of data discussed herein may be stored in a data store **314** in the memory **142** of the server(s) **108**, as illustrated in FIG. **3**.

Further, the backend-enrollment component **144** may cause a training component **316** to train one or more trained models **318**. The training component **316** may utilize the palm-feature data **310** to train the trained model(s) **318** to perform various operations for extracting and/or generating, from the image data **134**, palm-feature data **310**. The trained model(s) **318** may comprise any type of model, such as machine-learning models, including but not limited to artificial neural networks, classifiers, decision trees, support vector machines, Bayesian networks, and so forth.

As a specific example, the trained model(s) **318** may include or comprise one or more convolution neural networks (CNNs), recursive neural networks, and/or any other artificial networks, that are trained to analyze image data **134** received as input, and extract, determine, identify, generate, etc., palm-feature data **310** representing biometric characteristics of a palm of the user **106**. As a specific example, the palm-feature data **310** may comprise a 128-dimension feature vector representing the biometric characteristic(s) of the palm of the user **106**. In examples where the trained model(s) **318** include one or more CNNs, various functions may be utilized to transform the image data **134** into a metric space, such as a triplet loss function. Thus, the training component **316** may train the CNNs of the trained model(s) **318** using various functions, such as a triplet loss function, to extract, identity, or otherwise determine palm-feature data **310** from input image data **134**. Once in the metric space, extracted feature data may be compared, or matched, by computing a distance between the extracted feature data and feature data stored in the enrollment database **150**. For instance, when feature data is extracted from the image data **134** into palm-feature data **310** by the trained model(s) **318**, the extracted palm-feature data **310** may then be compared to stored data in the enrollment database **150** to identify a user profile for the user **106** represented in the input image data **134**. For instance, the extracted palm-feature data **310** may comprise a vector that is compared with stored vectors in the enrollment database **150** to identify which stored vectors have the smallest "distance" between the extracted feature data. The smaller the distance, the closer the strength of correspondence between the extracted feature data and the stored feature data representing users **106** that are enrolled for use of the user-recognition system. In some examples, other calculations may be performed, such as finding a cosine of an angle between two vectors, depending on the network utilized by the trained model(s) **318**. However, any type of models may be utilized for the trained model(s) **318**.

The palm-identification component **146** may include various sub-components for performing various operations. For instance, the palm-identification component **146** may include a palm-feature generation component **320** to extract or otherwise generate feature data from the image data **134**. The palm-feature generation component **320** may utilize the trained model(s) **318**, and/or include algorithms, to perform any type of feature extraction method, or embedding, to analyze the image data **134** and extract the palm-feature data **310**. For instance, the palm-feature generation component **320** may utilize state-of-the-art models, such as clustering, artificial neural networks, scale-invariant feature transform, edge detection, or any other type of extraction or embedding technology, to extract palm-feature data **310** from the image data **134**.

The palm-identification component **146** may further include a palm-feature aggregation component **322** configured to aggregate feature data for a user **106**. For instance, the palm-feature aggregation component **322** may combine palm-feature data **310** that has been extracted from a group of images depicting the user **106**, such as by averaging the features in the palm-feature data **310**.

Once a user **106** is enrolled for use of the user-recognition system, an identity-determination component **326** may be utilized to determine and/or verify an identity of a user **106** that interacted with a user-recognition device **104**. For example, the server(s) **108** may receive image data **134** from a user-recognition device **104** and the identity-determination component **326** may be configured to determine an identity of the user **106**, where the enrollment database **150** indicates the identity of the user **106** by, for example, indicating the user profile **312** that is associated with that user's identity.

The identity-determination component **326** may cause a palm-feature correspondence component **324** to perform various operations for determining or identifying a user **106** whose palm is depicted in the received image data **134**. For example, the palm-feature correspondence component **324** may compare the palm-feature data **310** for the received image data **134** with palm-feature data **310** stored in the enrollment database **150** for different user profiles **312** of users **106** enrolled in the user-recognition system in order to determine user profiles **312** for one or more users **106** whose respective palm-feature data **310** correspond to the extracted palm-feature data **310**. In some instances, the score calculated by the palm-feature correspondence component **324** may be compared to a threshold and, if the score is greater than the threshold, may result in identification of the user. If multiple user profiles are associated with scores that are greater than the threshold, then the user profile associated with the highest may be deemed to be associated with the image data **134** and/or further analysis may be performed to identify the appropriate user. Further, in some instances, the user-recognition system may employ set-reduction techniques to identify, based on an initial comparison, a top "N" group of user profiles **312** of users **106** whose respective palm-feature data **310** most strongly correspond to the extracted palm-feature data **310**. In some examples, a single user identity/profile **312** may be determined as corresponding to the input palm-feature data **310**. However, in some examples a group of top "N" candidates may be identified by the trained model(s) **318** as corresponding with a threshold amount of strength (e.g., 50% correspondence, 75% correspondence, etc.) to the extracted palm-feature data **310**. A second level of deeper analysis may then be performed to identify a single user from the "N" candidates.

Further, the memory **142** may store an enrollment-update component **148** configured to update the palm-feature data **310** stored in association with user profiles to allow for removal of stale feature data and use of more recent feature data and/or to otherwise allow for the update of the identification data (e.g., palm-feature data) stored in the enrollment database **150**. As introduced above, the enrollment-update component **148** may store both current identification data (e.g., palm-feature data) and palm-feature data used in recognition attempts and may periodically perform clustering techniques on this set for determining whether and/or how to update identification data for one or more of the user profiles **312**. An example operation of the enrollment-update component **148** is described below with reference to FIGS. **4A-4B**.

In addition, the memory **142** may store an audit component **330** configured to perform one or more auditing processes in response to occurrence of one or more predefined events. For example, the audit component **330** may perform a nightly auditing processes comprising rich comparison of palm-feature data associated with respective user profiles to one another to identify any errors previously made by the system. After identifying an error, the system may correct the error and may also use this information to further train the trained model(s) **318** utilizing techniques similar to those performed by the backend-enrollment component **144**. In some instances, the audit component **330** may perform the clustering techniques described above with reference to the enrollment-update component **148** in order to identify these errors.

Additionally, the memory **142** may store a quality-check component **328** which determines an overall metric of the quality of the extracted palm-feature data **310**. For instance, the quality-check component **328** may determine that additional image data **134** needs to be obtained for a user **106** for various reasons, such as a bandage or glove covering the palm of the user **106**, or the like. In some examples, the quality-check component **328** may utilize a trained model(s) **318** to determine whether a feature vector is of sufficient quality and, if not, may cause the user-recognition device to request additional image data **134**.

FIGS. **4A-4B** collectively illustrate an example process **400** for enrolling a user in the user-recognition system of FIG. **1**, as well as identifying the user thereafter and updating the enrollment of the user over time. As illustrated, in some instances the process **400** may be performed in whole or in part by one or more components accessible by the servers **108**. At an operation **402**, the servers **108** store image data and/or feature data generated based on the image data in an enrollment database for enrolling the user with the user-recognition system. For example, the servers may receive, from the user-recognition device **104** or another device, image data **404(1)** of a palm or other portion of the user and may generate featured data (e.g., in the form of a feature vector) using the image data. The servers **108** may thereafter store the image data **404(1)** and/or the feature data in the enrollment database **150** as "identification data" for a corresponding user profile. It is to be appreciated that while the illustrations depict the storing (and in some instances comparing) of image data rather than feature data, this is for ease of illustration and in other instances feature vectors or other forms of feature data may additionally or alternatively be stored and/or compared.

At an operation **406**, the servers may receive additional image data **404(2)** and/or corresponding feature data at a later time and may attempt to identify a user by matching the additional feature data to identification data (feature data) stored in the enrollment database **150**. For example, FIG. **4**A illustrates that the image data **404(2)** (and/or the corresponding feature data) may be compared to image data and/or feature data associated with a first user profile **408(1)**, to image data and/or feature data associated with a second user profile **408(2)**, to image data and/or feature data associated with a "Nth" user profile **408**(N), and so forth. In this example, the servers **108** determine, based on the comparison, that the image data **404(2)** corresponds to the user profile **408**(N) and, thus, to the corresponding user.

At an operation **410**, the enrollment update component **144** performs a clustering process on the stored feature data to generate cluster data **412**. As described above, the enrollment-update component **148** may perform this clustering process nightly or another periodicity, or in response to another triggering event. Further, the enrollment-update component **148** may perform this clustering process on identification data (e.g., feature data corresponding to image data **404(1)**) and other feature data previously received as part of a recognition attempt (e.g., feature data corresponding to image data **404(2)**).

FIG. **4**B continues the illustration of the process **400** and includes, at an operation **414**, the enrollment-update component **148** identifying one or more clusters in the cluster **412** and a corresponding minimum dominating set within each cluster. For instance, in this example the enrollment-update component **148** identifies a first cluster **416(1)**, consisting of six nodes, and a minimum dominating set **418(1)**, consisting of three of the six nodes. Again, each node may represent an individual feature data that has been determined to belong to the cluster **416(1)**.

An operation **420** concludes the process **400** and comprises the enrollment-update component **148** updating identification data in the enrollment database **150** using the dominating set(s). For instance, the enrollment-update component **148** may use one or more of the three nodes of the dominating set **418(1)** to update a user profile associated with the cluster **416(1)**.

FIG. **5** illustrates an example environment **500** including block diagram of one or more servers **108** configured to support at least a portion of the functionality of a user-recognition system, as well as an example flow of data within the system for enrolling a user **106** for use of the user-recognition system.

As illustrated, the environment **500** includes a client side **502** and a server side **504**. However, this is merely illustrative, and some or all of the techniques may be performed entirely on the client side **502**, or entirely on the server side **504**. At "1," a front-end enrollment component **132** may receive a request to enroll a user **106** for use of the user-recognition system. For example, the request may comprise various types of input, such as a selection made via an I/O interface **128** (e.g., touch screen, mouse, keyboard, etc.) of a user interface element presented on a display for starting an enrollment process. Additionally, the front-end enrollment component **132** may detect a speech utterance from the user **106** indicating a request to enroll (e.g., "please enroll me," "I would like to check out," etc.). Another request example may include the user **106** sliding a user ID card into an I/O interface **128**, such as a credit card, driver's license, etc. However, any type of input may be detected as a request by the front-end enrollment component **132**.

Upon receiving the request to enroll, the front-end enrollment component **132** may activate or otherwise utilize the imaging component(s) **126** to generate image data **134** representing a palm of the user **106**. At "2," the user-recognition device **104** then captures image data **134** and, at "3", sends the image data **134** to the server(s) **108**. For instance, the user-recognition device **104** may encode and send the audio data and image data **134** over the network(s) **138** to the server(s) **108**. Further, in some instances some of the images may be removed if they are not in focus, do not have a threshold level of discriminability of the characteristics of the palm of the user, or the like. This removal may occur on the client side **502** and/or the server side **504**.

At "4," the servers receive the image data and, at "5", the palm-feature generation component **320** may extract palm-feature data **310** from the image data **134**. In some examples, prior to extracting the palm-feature data **310**, the palm-feature generation component **320** may perform various operations for processing the image data **134** prior to extracting the palm-feature data **310**. For instance, the palm-feature generation component **320** may initially perform user detection to determine that the image data **134** represents a palm of a user **106**. For instance, the palm-feature generation component **320** may utilize an Integrated Sensor Processor (ISP) that performs hardware-based user detection techniques. In some examples, various software techniques may additionally, or alternatively be performed. In either instance, a bounding box may be output around the detected hand of the user **106** for an image depicting at least a portion of the user **106** and represented by the image data **134**. Further, the palm-feature generation component **320** may perform hand-pose estimation in order to align the palm of the user **106** with a common coordinate system. After aligning the image of the hand into a common coordinate section, the portion of the image data corresponding to the palm may be identified and cropped. This remaining portion of the image data may thereafter be used to extract features therefrom by, for example, running a neural network on the cropped section of the image data. In some examples, hand-pose estimation may improve the extraction of features representing the palm of the user **106**. Once the hand of the user **106** has been aligned, the palm-feature generation component **320** may extract features (e.g., palm-feature data **310**) from the image data **134**. In some examples, the trained model(s) **318** may utilize a triplet loss function which converts image data **134** into a feature embedding in a metric space (e.g., palm-feature data **310**), which may allow for comparisons with subsequent feature vectors using, for example, squared distance calculation.

At "6," the palm-feature aggregation component **322** may aggregate feature data (e.g., palm-feature data **310**) from various image data **134**. For instance, the image data **134** may represent the hand of the user **106** at different angles, under different lighting conditions, or other differing characteristics. The palm-feature aggregation component **322** may aggregate the palm-feature data **310** together, such as by averaging out feature vectors.

At "7," the quality-check component **328** may perform a quality check on the palm-feature data. For example, the quality-check component **328** may utilize a trained model(s) **318** to determine an overall metric of the quality of the extracted palm-feature data **310**. If the overall metric is poor, or below a threshold quality level, the user-recognition system may request to acquire additional image data **134**. In addition, or in the alternative, the quality-check component **328** may perform a de-duping process to ensure that the user associated with the palm-feature data hasn't already enrolled in the system. If the overall quality metric is good or acceptable, and if the de-duping process does not reveal that the user has previously enrolled in the system, the backend enrollment component **144** may aggregate the data at "8."

For example, at "8" the backend-enrollment component **144** may aggregate the palm-feature data **310** and enroll the user at "9" in the enrollment database **150**. The backend-enrollment component **144** may store associations (e.g., mappings) between the palm-feature data **310** with a user profile **312** of the user **106** requesting to be enrolled for use of the user-recognition system.

FIG. **6** illustrates an example environment **600** including a block diagram of one or more servers **108** configured to support at least a portion of the functionality of a user-recognition system, as well as an example flow of data within the system for identifying a user **106** of the user-recognition system and, potentially, updating the enrollment of the user. As illustrated, the environment **600** includes a client side **602** and a server side **604**. However, this is merely illustrative, and some or all of the techniques may be performed entirely on the client side **602**, or entirely on the server side **604**.

At "1," a user requests to sign in with the user-recognition system. For example, the presence-detection component **130** may be executable by the processor(s) **120** to detect a trigger indicating presence of the user **106**. The trigger detected by the presence-detection component **130** may comprise one or more types of input. For instance, the presence-detection component **130** may include logic to detect, using one or more imaging components **126**, a portion of a user **106** (e.g., a hand over the imaging component(s) **126** of the user-recognition device **104**). Other examples of triggers detected by the presence-detection component **130** that may indicate the presence of the user **106** may include receiving touch input (or other input, such as a mouse click) via one or more I/O interfaces **128** of the user-recognition device **104**. However, any type of input may be detected as a trigger by the presence-detection component **130**.

Upon identifying the request to sign in from the user, at "2" one or more imaging components **126** may generate image data **134** representing a palm of the user **106** and/or another portion of the user. At "3," the user-recognition device **104** may send the image data **134** to the server(s) **108**. For instance, the user-recognition device **104** may encode and send the image data **134** over the network(s) **138** to the server(s) **108**. Again, some of the image data **134** may be discarded based on the image data being out of focus, having a discriminability that is less than the threshold, and/or the like.

At "4," the servers may receive the image data **134** and, at "5", the palm-feature generation component **320** may extract palm-feature data **310** from the image data **134**. In some examples, prior to extracting the palm-feature data **310**, the palm-feature generation component **320** may perform various operations for processing the image data **134** prior to extracting the palm-feature data **310**. For instance, the palm-feature generation component **320** may initially perform palm detection to determine that the image data **134** represents a hand of a user **106**. For instance, the palm-feature generation component **320** may utilize an Integrated Sensor Processor (ISP) that performs hardware-based user detection techniques. In some examples, various software techniques may additionally, or alternatively be performed. In either instance, a bounding box may be output around the detected hand of the user **106** for an image depicting the user **106** and represented by the image data **134**. Further, the palm-feature generation component **320** may perform hand pose estimation to align the face of the user **106** with a common coordinate system. In some examples, hand pose estimation may improve the extraction of features representing the hand of the user **106**. Once the hand of the user **106** has been aligned, the palm-feature generation component **320** may extract features (e.g., palm-feature data **310**) from the image data **134**. In some examples, the trained model(s) **318** may utilize a triplet loss function which converts the image data **134** into a feature embedding in a metric space (e.g., palm-feature data **310**), which may allow for comparisons with subsequent feature vectors using, for example, squared distance calculation.

At "6," the palm-feature aggregation component **322** may aggregate feature data (e.g., palm-feature data **310**) from various image data **134**. For instance, the image data **134** may represent the hand of the user **106** at different angles, under different lighting conditions, or other differing characteristics. The palm-feature aggregation component **322** may aggregate the palm-feature data **310** together, such as by averaging out feature vectors.

At "7," the palm-feature correspondence component **324** may generate one or more scores indicating a similarity between the aggregated features associated with the image data **134** and respective feature data stored in association with respective user profiles. In some examples, these correspondence scores may be determined, at least in part, on "distances" between the feature vector associated with the image data and respective feature vectors of the respective palm-feature data **310** stored in association with user profiles in the enrollment database **150**.

At "8," the identity-determination component **326** may determine the identity of the user based on the correspondence scores. For example, the identity-determination component **326** may identity the user profile associated with the feature vector having the closest distance to the feature vector associated with the image data **134** and may deem the associated user the user associated with the image data **134**.

At "9", in some instances the enrollment-update component **148** may update identification data stored in the enrollment database **150**, such as nightly, weekly, or the like, or in response to detecting occurrence of a predefined event that results in the updating of the enrollment database **150**.

At "10", the enrollment-update component **148** updates the identification data associated with one or more user profiles in the enrollment database **150**. As described above, this may include storing the new identification data and/or image data alongside existing identification data and/or image data associated with the profile, averaging the existing identification data with the new identification data, and/or the like.

FIG. **7** illustrates a flow diagram of an example process **700** for updating stored palm-feature data **310** for a user profile **312** of a user-recognition system. In some examples, the process **700** may be performed at least partly by the enrollment-update component **148**. In some examples, additional steps, or less steps, may be performed to update the palm-feature data **310**.

At an operation **702**, the enrollment-update component **148** may obtain image data **134** for a user **106** of a user-recognition system. In some examples, the image data **134** may be obtained for each occurrence where an enrolled user **106** at least one of enters or exits a facility **102** using a user-recognition device **104**. Additionally, or alternatively, the enrollment-update component **148** may obtain image data **134** from one or more use devices **712** (e.g., phone, tablet, laptop, etc.) associated with the user **106**.

At an operation **704**, the enrollment-update component **148** may detect an event that triggers an update of palm-feature data **310** stored in an enrollment database **150** that is used to identify the user **106**. The event may comprise any type of event that indicates that the enrollment-update component **148** is to update the stored palm-feature data **310** in the enrollment database **150**. For example, the event may comprise a periodic event where the enrollment-update component **148** updates the palm-feature data **310** according to a predefined schedule (e.g., every month, every six months, etc.). In some examples, the enrollment-update component **148** may detect an event when sufficient images have been obtained since a previous update of the palm-feature data **310**. For example, once the enrollment-update component **148** has collected more than a threshold number of images and/or videos (e.g., 10 images, 100 images, etc.), the enrollment-update component **148** may determine to update the palm-feature data **310**.

At an operation **706**, the enrollment-update component **148** may select a subset of images (or feature data generated therefrom) from the obtained image data **134** to be used to update the palm-feature data **310**. In some examples, the enrollment-update component **148** may select the subset as those feature data associated with a dominating set of a cluster as described above. In addition, or in the alternative, the enrollment-update component **148** may select (or filter) feature data or image data based on a respective quality of the images, such as whether each image was in-focus, whether the image has a high discriminability (that is, does well to illustrate creases, veins, etc.), whether the hand is oriented correctly (e.g., in a substantially parallel plane to the imaging components **126**), or the like.

At an operation **708**, the enrollment-update component **148** may extract feature data (e.g., palm-feature data **310**) from the subset of the images. For instance, the enrollment-update component **148** may call the palm-feature generation component **320** to extract, or embed, palm-feature data **310** from the image data **134** for the subset of the images. The palm-feature generation component **320** may extract the palm-feature data **310** from the image data **134** into any format, such as a feature descriptor **714** (e.g., a 128-dimension vector), a feature matrix, and/or any other representation.

At an operation **710**, the enrollment-update component **148** may update the palm-feature generation component **320** stored in the enrollment database **150** using the feature data (e.g., palm-feature data **310**) extracted from the subset of the images included in the image data **134**. For example, the enrollment-update component **148** may average the extracted palm-feature data **310** with the palm-feature data **310** stored in the enrollment database **150**. In some examples, the enrollment-update component **148** may replace the palm-feature data **310** stored in the enrollment database **150** with the extracted palm-feature data **310**. In some examples, the enrollment-update component **148** may store the extracted palm-feature data **310** in the enrollment database **150** along with the previously stored palm-feature data **310**, thereby storing at least two feature vectors, or representations. In other instances, the enrollment-update component **148** may merge the feature data, as described above.

FIGS. **8**A-**8**B collectively illustrate a flow diagram of an example process **800** for enrolling a user in a user-recognition system and updating this enrollment over time. The process **800**, as well as the additional processes discussed herein, may be implemented in hardware, software, or a combination thereof. In the context of software, the described operations represent computer-executable instructions stored on one or more computer-readable storage media that, when executed by one or more hardware processors, perform the recited operations. Generally, computer-executable instructions include routines, programs, objects, components, data structures, and the like that perform particular functions or implement particular abstract data types. Those having ordinary skill in the art will readily recognize that certain steps or operations illustrated in the figures above may be eliminated, combined, or performed in an alternate order. Any steps or operations may be performed serially or in parallel. Furthermore, the order in which the operations are described is not intended to be construed as a limitation. In some instances, the processes described herein may be performed, in whole or in part, by the servers **108**, the user-recognition device **104**, and/or a combination thereof.

The process **800** includes, at an operation **802**, storing multiple feature data, each respective feature data being generated from respective image data of a palm of a respective user. This operation may comprise storing both identification data (e.g., feature data generated at a time of enrollment) and feature data generated from image data associated with recognition attempts.

At an operation **804**, the enrollment-update component **148** determines whether to apply a clustering algorithm to the multiple feature data. For instance, this operation may comprise determining whether a trigger to begin the update process has been received. If not, the process **800** returns to storing incoming feature data. If so, however, then the process **800** proceeds to an operation **806**.

At the operation **806**, the enrollment-update component **148** applies a clustering algorithm to the multiple feature data to generate cluster data. This operation may comprise applying the clustering algorithm to generate the cluster data, which indicates a connection between an individual feature data and each other feature data having a computed similarity to the individual feature data that is greater than a threshold similarity. As described above, each computed similarity may be based on a mathematical distance between two feature data.

At an operation **808**, the enrollment-update component **148** determines each cluster from the cluster data. That is, the enrollment-update component **148** may identify respective groups of multiple feature data (or nodes) connected together as indicated by the cluster data. In some instances, the output of the clustering algorithm is cluster data that groups together the nodes in the respective clusters.

At an operation **810**, the enrollment-update component **148** determines a dominating set for a first identified cluster represented by the cluster data, wherein the first identified cluster is associated with a particular user profile. As described above, determining a dominating set may comprise identifying which nodes collectively represent a minimum of nodes that are directly connected to each other non-dominating-set node in the cluster.

At an operation **812**, the enrollment-update component **148** may generate identification data using feature data of the dominating set. For instance, the enrollment-update component **148** may compute an average feature data from each feature data of the dominating set and store this average feature data as the identification data in association with the particular user profile. In another example, the enrollment-update component **148** may generate the identification data by merging previous identification data associated with the particular user profile with feature data of the dominating set.

At an operation **814**, the enrollment-update component **148** stores the identification data in association with the first user profile. For instance, the enrollment-update component **148** may store the new identification data in association with the user profile in the enrollment database **150**.

At an operation **816**, the enrollment-update component **148** determines whether the cluster data indicates at least one additional cluster. If so, the process **800** returns to the operation **810** for determining a minimum dominating set for a next cluster. If not, then process **800** proceeds to an operation **818**. In other words, the operation **816** may represent that the process **800** may update the identification data for each cluster identified in the cluster data.

At the operation **818**, the palm-identification component **146** receives subsequent feature data generated from subsequent image data of a palm of a user. For instance, the palm-identification component **146** may receive this subsequent feature data as part of a recognition attempt by a user operating the user-recognition device **104**.

FIG. **8**B continues the illustration of the process **800** and includes, at an operation **820**, the palm-identification component **146** analyzing the subsequent feature data with regards to the identification data, such as identification data associated with multiple user profiles. For instance, the palm-identification component **146** may compare the subsequent feature data to each of multiple identification data to generate respective similarity scores.

At an operation **822**, the palm-identification component **146** determines whether it has identified a user profile based on the comparison. For instance, this operation may comprise determining whether any of the similarity scores are greater than a threshold. If so, then the process proceeds to an operation **824**.

At an operation **824**, the palm-identification component **146** stores, based at least part on the analyzing, an indication that the subsequent feature data corresponds to the identified user profile. That is, the palm-identification component **146** may select the user profile associated with a highest similarity score and may store an indication that the subsequent feature data corresponds to this user profile.

At an operation **826**, the palm-identification component **146** may output an indication that the subsequent feature data corresponds to the identified user profile. For instance, the component **146**, or another component, may send an instruction to the user-recognition to output an indication that a match has occurred, may charge a payment instrument associated with the user profile for a transaction, and/or the like.

If, however, the palm-identification component **146** does not identify a matching user profile at the operation **822**, then at an operation **828**, the palm-identification component **146** stores an indication that the subsequent feature data is unknown. In addition, at an operation **830**, the palm-identification component **146** may output an indication that the subsequent data is unknown. This may include sending an instruction to the user-recognition device **104** to output an indication that no match has been, requesting the user to try again, requesting the user to enroll with the user-recognition system, and/or the like.

FIG. **9** illustrates another flow diagram of an example process **900** for enrolling a user in a user-recognition system and updating this enrollment over time. The process **900** includes, at an operation **902**, storing a set of feature data, each individual feature data of the set of feature data generated based on respective image data.

An operation **904** represents the enrollment-update component **148** clustering the set of feature data to determine at least a first cluster of feature data, the first cluster being associated with a first user profile. In some instances, the clustering may result in multiple clusters, each associated with a respective user profile. In some instances, this operation comprises comparing each individual feature data of the set of feature data to each other individual feature data of the set of feature data to compute a similarity score therebetween and generating cluster data representing a graph connecting each two feature data having a respective similarity score that is greater than a threshold similarity score.

At an operation **906**, the enrollment-update component **148** selects one or more feature data of the first cluster. In some instances, this selecting comprises selecting feature data associated with a dominating set of the first cluster.

At an operation **908**, the enrollment-update component **148** generates identification data based at least in part on the one or more feature data. In some instances, this comprises generating the identification data based at least in part on the one or more feature data and previous identification data stored in association with the first user profile. In other instances, this may comprise storing the one or more feature data as the identification data. In still other instances, this may comprise generating the identification data based as an average of each feature data of multiple feature data.

At an operation **910**, the enrollment-update component **148** stores the identification data in association with the first user profile. For instance, the enrollment-update component **148** may store the identification data in association with the user profile in the enrollment database **150**.

At an operation **912**, the palm-identification component **146** receives subsequent feature data generated from subsequent image data associated with a user. For instance, the palm-identification component **146** may receive this subsequent feature data as part of a recognition attempt by a user operating the user-recognition device **104**.

At an operation **914**, the palm-identification component **146** analyzes the subsequent feature data with regards to the identification data. For instance, the palm-identification component **146** may compare the subsequent feature data to each of multiple identification data to generate respective similarity scores.

At an operation **916**, the palm-identification component **146** stores, based at least part on the analyzing, an indication that the subsequent feature data corresponds to the first user profile. That is, the palm-identification component **146** may select the user profile associated with a highest similarity score and may store an indication that the subsequent feature data corresponds to this user profile.

At an operation **918**, the palm-identification component **146**, or another component, outputs an indication that the subsequent feature data corresponds to the first user profile. For instance, the component **146**, or another component, may send an instruction to the user-recognition to output an indication that a match has occurred, may charge a payment instrument associated with the user profile for a transaction, and/or the like.

Embodiments may be provided as a software program or computer program product including a non-transitory computer-readable storage medium having stored thereon instructions (in compressed or uncompressed form) that may be used to program a computer (or other electronic device) to perform processes or methods described herein. The computer-readable storage medium may be one or more of an electronic storage medium, a magnetic storage medium, an optical storage medium, a quantum storage medium, and so forth. For example, the computer-readable storage media may include, but is not limited to, hard drives, floppy diskettes, optical disks, read-only memories (ROMs), random access memories (RAMs), erasable programmable ROMs (EPROMs), electrically erasable programmable ROMs (EEPROMs), flash memory, magnetic or optical cards, solid-state memory devices, or other types of physical media suitable for storing electronic instructions. Further, embodiments may also be provided as a computer program product including a transitory machine-readable signal (in compressed or uncompressed form). Examples of machine-readable signals, whether modulated using a carrier or unmodulated, include, but are not limited to, signals that a computer system or machine hosting or running a computer program can be configured to access, including signals transferred by one or more networks. For example, the transitory machine-readable signal may comprise transmission of software by the Internet.

Separate instances of these programs can be executed on or distributed across any number of separate computer systems. Thus, although certain steps have been described as being performed by certain devices, software programs, processes, or entities, this need not be the case, and a variety of alternative implementations will be understood by those having ordinary skill in the art.

Additionally, those having ordinary skill in the art readily recognize that the techniques described above can be utilized in a variety of devices, environments, and situations. Although the subject matter has been described in language specific to structural features or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described. Rather, the specific features and acts are disclosed as exemplary forms of implementing the claims.

FIGS. **10** and **11** represent an illustrative materials handling environment, such as the materials handling facility **102**, in which the techniques described herein may be applied to cameras monitoring the environments as described below. However, the following description is merely one illustrative example of an industry and environment in which the techniques described herein may be utilized.

An implementation of a materials handling facility **1002** (e.g., facility **102**) configured to store and manage inventory items is illustrated in FIG. **10**. A materials handling facility **1002** (facility) comprises one or more physical structures or areas within which one or more items **1004(1)**, **1004(2)**, . . . , **1004**(Q) (generally denoted as **1004**) may be held. As used in this disclosure, letters in parenthesis such as "(Q)" indicate an integer result. The items **1004** comprise physical goods, such as books, pharmaceuticals, repair parts, electronic gear, groceries, and so forth.

The facility **1002** may include one or more areas designated for different functions with regard to inventory handling. In this illustration, the facility **1002** includes a receiving area **1006**, a storage area **1008**, and a transition area **1010**. The receiving area **1006** may be configured to accept items **1004**, such as from suppliers, for intake into the facility **1002**. For example, the receiving area **1006** may include a loading dock at which trucks or other freight conveyances unload the items **1004**.

The storage area **1008** is configured to store the items **1004**. The storage area **1008** may be arranged in various physical configurations. In one implementation, the storage area **1008** may include one or more aisles **1012**. The aisle **1012** may be configured with, or defined by, inventory locations **1014** on one or both sides of the aisle **1012**. The inventory locations **1014** may include one or more of shelves, racks, cases, cabinets, bins, floor locations, or other suitable storage mechanisms for holding or storing the items **1004**. The inventory locations **1014** may be affixed to the floor or another portion of the facility's structure, or may be movable such that the arrangements of aisles **1012** may be reconfigurable. In some implementations, the inventory locations **1014** may be configured to move independently of an outside operator. For example, the inventory locations **1014** may comprise a rack with a power source and a motor, operable by a computing device to allow the rack to move from one location within the facility **1002** to another.

One or more users **1016(1)**, **1016(2)**, . . . , **1016**(U), totes **1018(1)**, **1018(2)**, . . . , **1018**(T) (generally denoted as **1018**) or other material handling apparatus may move within the facility **1002**. For example, the users **1016** may move about within the facility **1002** to pick or place the items **1004** in various inventory locations **1014**, placing them on the totes **1018** for ease of transport. An individual tote **1018** is configured to carry or otherwise transport one or more items **1004**. For example, a tote **1018** may include a basket, a cart, a bag, and so forth. In other implementations, other agencies such as robots, forklifts, cranes, aerial drones, and so forth, may move about the facility **1002** picking, placing, or otherwise moving the items **1004**.

One or more sensors **1020** may be configured to acquire information in the facility **1002**. The sensors **1020** in the facility **1002** may include sensors fixed in the environment (e.g., ceiling-mounted cameras) or otherwise, such as sensors in the possession of users (e.g., mobile phones, tablets, etc.). The sensors **1020** may include, but are not limited to, cameras **1020(1)**, weight sensors, radio frequency (RF) receivers, temperature sensors, humidity sensors, vibration sensors, and so forth. The sensors **1020** may be stationary or mobile, relative to the facility **1002**. For example, the inventory locations **1014** may contain cameras **1020(1)** configured to acquire images of pick or placement of items **1004** on shelves, of the users **1016(1)** and **1016(2)** in the facility **1002**, and so forth. In another example, the floor of the facility **1002** may include weight sensors configured to determine a weight of the users **1016** or other object thereupon.

During operation of the facility **1002**, the sensors **1020** may be configured to provide information suitable for identifying new locations of objects or other occurrences within the facility **1002**. For example, a series of images acquired by a camera **1020(1)** may indicate removal of an item **1004** from a particular inventory location **1014** by one of the users **1016** and placement of the item **1004** on or at least partially within one of the totes **1018**.

While the storage area **1008** is depicted as having one or more aisles **1012**, inventory locations **1014** storing the items **1004**, sensors **1020**, and so forth, it is understood that the receiving area **1006**, the transition area **1010**, or other areas of the facility **1002** may be similarly equipped. Furthermore, the arrangement of the various areas within the facility **1002** is depicted functionally rather than schematically. For example, multiple different receiving areas **1006**, storage areas **1008**, and transition areas **1010** may be interspersed rather than segregated in the facility **1002**.

The facility **1002** may include, or be coupled to, an inventory management system **1022**. The inventory management system **1022** is configured to identify interactions with and between users **1016**, devices such as sensors **1020**, robots, material handling equipment, computing devices, and so forth, in one or more of the receiving area **1006**, the storage area **1008**, or the transition area **1010**. These interactions may include one or more events **1024**. For example, events **1024** may include the entry of the user **1016** to the facility **1002**, stocking of items **1004** at an inventory location **1014**, picking of an item **1004** from an inventory location **1014**, returning of an item **1004** to an inventory location **1014**, placement of an item **1004** within a tote **1018**, movement of users **1016** relative to one another, gestures by the users **1016**, and so forth. Other events **1024** involving users **1016** may include the user **1016** providing authentication information in the facility **1002**, using a computing device at the facility **1002** to authenticate identity to the inventory management system **1022**, and so forth. Some events **1024** may involve one or more other objects within the facility **1002**. For example, the event **1024** may comprise movement within the facility **1002** of an inventory location **1014**, such as a counter mounted on wheels. Events **1024** may involve one or more of the sensors **1020**. For example, a change in operation of a sensor **1020**, such as a sensor failure, change in alignment, and so forth, may be designated as an event **1024**. Continuing the example, movement of a camera **1020(1)** resulting in a change in the orientation of the field of view **1028** (such as resulting from someone or something bumping the camera **1020(1)**) (e.g. camera) may be designated as an event **1024**.

By determining the occurrence of one or more of the events **1024**, the inventory management system **1022** may generate output data **1026**. The output data **1026** comprises information about the event **1024**. For example, where the event **1024** comprises an item **1004** being removed from an inventory location **1014**, the output data **1026** may comprise an item identifier indicative of the particular item **1004** that was removed from the inventory location **1014** and a user identifier of a user that removed the item.

The inventory management system **1022** may use one or more automated systems to generate the output data **1026**. For example, an artificial neural network, one or more classifiers, or other automated machine learning techniques may be used to process the sensor data from the one or more sensors **1020** to generate output data **1026**. The automated systems may operate using probabilistic or non-probabilistic techniques. For example, the automated systems may use a Bayesian network. In another example, the automated systems may use support vector machines to generate the output data **1026** or the tentative results. The automated systems may generate confidence level data that provides information indicative of the accuracy or confidence that the output data **1026** or the tentative data corresponds to the physical world.

The confidence level data may be generated using a variety of techniques, based at least in part on the type of automated system in use. For example, a probabilistic system using a Bayesian network may use a probability assigned to the output as the confidence level. Continuing the example, the Bayesian network may indicate that the probability that the item depicted in the image data corresponds to an item previously stored in memory is 135%. This probability may be used as the confidence level for that item as depicted in the image data.

In another example, output from non-probabilistic techniques such as support vector machines may have confidence levels based on a distance in a mathematical space within which the image data of the item and the images of previously stored items have been classified. The greater the distance in this space from a reference point such as the previously stored image to the image data acquired during the occurrence, the lower the confidence level.

In yet another example, the image data of an object such as an item **1004**, user **1016**, and so forth, may be compared with a set of previously stored images. Differences between the image data and the previously stored images may be assessed. For example, differences in shape, color, relative proportions between features in the images, and so forth. The differences may be expressed in terms of distance with a mathematical space. For example, the color of the object as depicted in the image data and the color of the object as depicted in the previously stored images may be represented as coordinates within a color space.

The confidence level may be determined based at least in part on these differences. For example, the user **1016** may pick an item **1004(1)** such as a perfume bottle that is generally cubical in shape from the inventory location **1014**. Other items **1004** at nearby inventory locations **1014** may be predominately spherical. Based on the difference in shape (cube vs. sphere) from the adjacent items, and the correspondence in shape with the previously stored image of the perfume bottle item **1004(1)** (cubical and cubical), the confidence level that the user **1016** has picked up the perfume bottle item **1004(1)** is high.

In some situations, the automated techniques may be unable to generate output data **1026** with a confidence level above a threshold result. For example, the automated techniques may be unable to distinguish which user **1016** in a crowd of users **1016** has picked up the item **1004** from the inventory location **1014**. In other situations, it may be desirable to provide human confirmation of the event **1024** or of the accuracy of the output data **1026**. For example, some items **1004** may be deemed age restricted such that they are to be handled only by users **1016** above a minimum age threshold.

In instances where human confirmation is desired, sensor data associated with an event **1024** may be processed to generate inquiry data. The inquiry data may include a subset of the sensor data associated with the event **1024**. The inquiry data may also include one or more of one or more tentative results as determined by the automated techniques, or supplemental data. The subset of the sensor data may be determined using information about the one or more sensors **1020**. For example, camera data such as the location of the camera **1020(1)** within the facility **1002**, the orientation of the camera **1020(1)**, and a field of view **1028** of the camera **1020(1)** may be used to determine if a particular location within the facility **1002** is within the field of view **1028**. The subset of the sensor data may include images that may show the inventory location **1014** or that the item **1004** was stowed. The subset of the sensor data may also omit images from other cameras **1020(1)** that did not have that inventory location **1014** in the field of view **1028**. The field of view **1028** may comprise a portion of the scene in the facility **1002** that the sensor **1020** is able to generate sensor data about.

Continuing the example, the subset of the sensor data may comprise a video clip acquired by one or more cameras **1020**(1) having a field of view **1028** that includes the item **1004**. The tentative results may comprise the "best guess" as to which items **1004** may have been involved in the event **1024**. For example, the tentative results may comprise results determined by the automated system that have a confidence level above a minimum threshold.

The facility **1002** may be configured to receive different kinds of items **1004** from various suppliers and to store them until a customer orders or retrieves one or more of the items **1004**. A general flow of items **1004** through the facility **1002** is indicated by the arrows of FIG. **10**. Specifically, as illustrated in this example, items **1004** may be received from one or more suppliers, such as manufacturers, distributors, wholesalers, and so forth, at the receiving area **1006**. In various implementations, the items **1004** may include merchandise, commodities, perishables, or any suitable type of item **1004**, depending on the nature of the enterprise that operates the facility **1002**. The receiving of the items **1004** may comprise one or more events **1024** for which the inventory management system **1022** may generate output data **1026**.

Upon being received from a supplier at receiving area **1006**, the items **1004** may be prepared for storage. For example, items **1004** may be unpacked or otherwise rearranged. The inventory management system **1022** may include one or more software applications executing on a computer system to provide inventory management functions based on the events **1024** associated with the unpacking or rearrangement. These inventory management functions may include maintaining information indicative of the type, quantity, condition, cost, location, weight, or any other suitable parameters with respect to the items **1004**. The items **1004** may be stocked, managed, or dispensed in terms of countable, individual units or multiples, such as packages, cartons, crates, pallets, or other suitable aggregations. Alternatively, some items **1004**, such as bulk products, commodities, and so forth, may be stored in continuous or arbitrarily divisible amounts that may not be inherently organized into countable units. Such items **1004** may be managed in terms of measurable quantity such as units of length, area, volume, weight, time, duration, or other dimensional properties characterized by units of measurement. Generally speaking, a quantity of an item **1004** may refer to either a countable number of individual or aggregate units of an item **1004** or a measurable amount of an item **1004**, as appropriate.

After arriving through the receiving area **1006**, items **1004** may be stored within the storage area **1008**. In some implementations, like items **1004** may be stored or displayed together in the inventory locations **1014** such as in bins, on shelves, hanging from pegboards, and so forth. In this implementation, all items **1004** of a given kind are stored in one inventory location **1014**. In other implementations, like items **1004** may be stored in different inventory locations **1014**. For example, to optimize retrieval of certain items **1004** having frequent turnover within a large physical facility **1002**, those items **1004** may be stored in several different inventory locations **1014** to reduce congestion that might occur at a single inventory location **1014**. Storage of the items **1004** and their respective inventory locations **1014** may comprise one or more events **1024**.

When a customer order specifying one or more items **1004** is received, or as a user **1016** progresses through the facility **1002**, the corresponding items **1004** may be selected or "picked" from the inventory locations **1014** containing those items **1004**. In various implementations, item picking may range from manual to completely automated picking. For example, in one implementation, a user **1016** may have a list of items **1004** they desire and may progress through the facility **1002** picking items **1004** from inventory locations **1014** within the storage area **1008**, and placing those items **1004** into a tote **1018**. In other implementations, employees of the facility **1002** may pick items **1004** using written or electronic pick lists derived from customer orders. These picked items **1004** may be placed into the tote **1018** as the employee progresses through the facility **1002**. Picking may comprise one or more events **1024**, such as the user **1016** in moving to the inventory location **1014**, retrieval of the item **1004** from the inventory location **1014**, and so forth.

After items **1004** have been picked, they may be processed at a transition area **1010**. The transition area **1010** may be any designated area within the facility **1002** where items **1004** are transitioned from one location to another or from one entity to another. For example, the transition area **1010** may be a packing station within the facility **1002**. When the item **1004** arrives at the transition area **1010**, the items **1004** may be transitioned from the storage area **1008** to the packing station. The transitioning may comprise one or more events **1024**. Information about the transition may be maintained by the inventory management system **1022** using the output data **1026** associated with those events **1024**.

In another example, if the items **1004** are departing the facility **1002** a list of the items **1004** may be obtained and used by the inventory management system **1022** to transition responsibility for, or custody of, the items **1004** from the facility **1002** to another entity. For example, a carrier may accept the items **1004** for transport with that carrier accepting responsibility for the items **1004** indicated in the list. In another example, a customer may purchase or rent the items **1004** and remove the items **1004** from the facility **1002**. The purchase or rental may comprise one or more events **1024**.

The inventory management system **1022** may access or generate sensor data about the facility **1002** and the contents therein including the items **1004**, the users **1016**, the totes **1018**, and so forth. The sensor data may be acquired by one or more of the sensors **1020**, data provided by other systems, and so forth. For example, the sensors **1020** may include cameras **1020(1)** configured to acquire image data of scenes in the facility **1002**. The image data may comprise still images, video, or a combination thereof. The image data may be processed by the inventory management system **1022** to determine a location of the user **1016**, the tote **1018**, the identity of the user **1016**, and so forth. As used herein, the identity of the user may represent a unique identifier of the user (e.g., name, number associated with user, username, etc.), an identifier that distinguishes the user amongst other users being identified with the environment, or the like.

The inventory management system **1022**, or systems coupled thereto, may be configured to identify the user **1016**, as well as to determine other candidate users. In one implementation, this determination may comprise comparing sensor data with previously stored identity data. For example, the user **1016** may be identified by showing their face to a facial recognition system, by presenting a token carrying authentication credentials, providing a fingerprint, scanning a barcode or other type of unique identifier upon entering the facility, and so forth. Identity of the user **1016** may be determined before, during, or after entry to the facility **1002**. Determination of the user's **1016** identity may comprise comparing sensor data associated with the user **1016** in the facility **1002** to previously stored user data.

In some instances, the inventory management system group users within the facility into respective sessions. That is, the inventory management system **1022** may utilize the sensor data to determine groups of users that are effectively "together" (e.g., shopping together). In some instances, a particular session may include multiple users that entered the facility **1002** together and, potentially, that navigate the facility together. For example, when a family of two adults and two children enter the facility together, the inventory management system may associate each user with a particular session. Locating sessions in addition to individual users may help in determining the outcome of individual events, given that users within a session may not only individually pick or return or otherwise interact with items, but may also pass the items back and forth amongst each other. For instance, a child in the above example may pick the box of cereal before handing the box to her mother, who may place it in her tote **1018**. Noting the child and the mother as belonging to the same session may increase the chances of successfully adding the box of cereal to the virtual shopping cart of the mother.

By determining the occurrence of one or more events **1024** and the output data **1026** associated therewith, the inventory management system **1022** is able to provide one or more services to the users **1016** of the facility **1002**. By utilizing one or more human associates to process inquiry data and generate response data that may then be used to produce output data **1026**, overall accuracy of the system may be enhanced. The enhanced accuracy may improve the user experience of the one or more users **1016** of the facility **1002**. In some examples, the output data **1026** may be transmitted over a network **1030** to one or more servers **108**.

FIG. **11** illustrates a block diagram of the one or more servers **108**. The servers **108** may be physically present at the facility **1002**, may be accessible by the network **1030**, or a combination of both. The servers **108** do not require end-user knowledge of the physical location and configuration of the system that delivers the services. Common expressions associated with the servers **108** may include "on-demand computing," "software as a service (SaaS)," "cloud services," "data centers," and so forth. Services provided by the servers **108** may be distributed across one or more physical or virtual devices.

The servers **108** may include one or more hardware processors **1102** (processors) configured to execute one or more stored instructions. The processors **1102** may comprise one or more cores. The servers **108** may include one or more input/output (I/O) interface(s) **1104** to allow the processor **1102** or other portions of the servers **108** to communicate with other devices. The I/O interfaces **1104** may comprise Inter-Integrated Circuit (I2C), Serial Peripheral Interface bus (SPI), Universal Serial Bus (USB) as promulgated by the USB Implementers Forum, and so forth.

The servers **108** may also include one or more communication interfaces **1108**. The communication interfaces **1108** are configured to provide communications between the servers **108** and other devices, such as the sensors **1020**, the interface devices, routers, and so forth. The communication interfaces **1106** may include devices configured to couple to personal area networks (PANs), wired and wireless local area networks (LANs), wired and wireless wide area networks (WANs), and so forth. For example, the communication interfaces **1108** may include devices compatible with Ethernet, Wi-Fi™, and so forth. The servers **108** may also include one or more busses or other internal communications hardware or software that allow for the transfer of data between the various modules and components of the servers **108**.

The servers **108** may also include a power supply **1140**. The power supply **1140** is configured to provide electrical power suitable for operating the components in the servers **108**.

As shown in FIG. **11**, the servers **108** includes one or more memories **1110**. The memory **1110** comprises one or more computer-readable storage media (CRSM). The CRSM may be any one or more of an electronic storage medium, a magnetic storage medium, an optical storage medium, a quantum storage medium, a mechanical computer storage medium, and so forth. The memory **1110** provides storage of computer-readable instructions, data structures, program modules, and other data for the operation of the servers **108**. A few example functional modules are shown stored in the memory **1110**, although the same functionality may alternatively be implemented in hardware, firmware, or as a system on a chip (SOC).

The memory **1110** may include at least one operating system (OS) component **1112**. The OS component **1112** is configured to manage hardware resource devices such as the I/O interfaces **1104**, the communication interfaces **1108**, and provide various services to applications or components executing on the processors **1102**. The OS component **1112** may implement a variant of the FreeBSD™ operating system as promulgated by the FreeBSD Project; other UNIX™ or UNIX-like variants; a variation of the Linux™ operating system as promulgated by Linus Torvalds; the Windows® Server operating system from Microsoft Corporation of Redmond, Wash., USA; and so forth.

One or more of the following components may also be stored in the memory **1110**. These components may be executed as foreground applications, background tasks, daemons, and so forth. A communication component **1114** may be configured to establish communications with one or more of the sensors **1020**, one or more of the devices used by associates, other servers **108**, or other devices. The communications may be authenticated, encrypted, and so forth.

The memory **1110** may store an inventory management system **1116**. The inventory management system **1116** is configured to provide the inventory functions as described herein with regard to the inventory management system **1022**. For example, the inventory management system **1116** may determine movement of items **1004** in the facility **1002**, generate user interface data, and so forth.

The inventory management system **1116** may access information stored in one or more data stores **1118** in the memory **1110**. The data store **1118** may use a flat file, database, linked list, tree, executable code, script, or other data structure to store the information. In some implementations, the data store **1118** or a portion of the data store **1118** may be distributed across one or more other devices including other servers **108**, network attached storage devices, and so forth.

The data store **1118** may include physical layout data **1120**. The physical layout data **1120** provides a mapping of physical locations within the physical layout of devices and objects such as the sensors **1020**, inventory locations **1014**, and so forth. The physical layout data **1120** may indicate the coordinates within the facility **1002** of an inventory location **1014**, sensors **1020** within view of that inventory location **1014**, and so forth. For example, the physical layout data **1120** may include camera data comprising one or more of a location within the facility **1002** of a camera **1020(1)**, orientation of the camera **1020(1)**, the operational status, and so forth. Continuing example, the physical layout data **1120** may indicate the coordinates of the camera **1020**(**1**), pan and tilt information indicative of a direction that the field of view **1028** is oriented along, whether the camera **1020**(**1**) is operating or malfunctioning, and so forth.

In some implementations, the inventory management system **1116** may access the physical layout data **1120** to determine if a location associated with the event **1024** is within the field of view **1028** of one or more sensors **1020**. Continuing the example above, given the location within the facility **1002** of the event **1024** and the camera data, the inventory management system **1116** may determine the cameras **1020**(**1**) that may have generated images of the event **1024**.

The item data **1122** comprises information associated with the items **1004**. The information may include information indicative of one or more inventory locations **1014** at which one or more of the items **1004** are stored. The item data **1122** may also include order data, SKU or other product identifier, price, quantity on hand, weight, expiration date, images of the item **1004**, detail description information, ratings, ranking, and so forth. The inventory management system **1116** may store information associated with inventory management functions in the item data **1122**.

The data store **1118** may also include sensor data **1124**. The sensor data **1124** comprises information acquired from, or based on, the one or more sensors **1020**. For example, the sensor data **1124** may comprise 3D information about an object in the facility **1002**. As described above, the sensors **1020** may include a camera **1020**(**1**), which is configured to acquire one or more images. These images may be stored as the image data **1126**. The image data **1126** may comprise information descriptive of a plurality of picture elements or pixels. Non-image data **1128** may comprise information from other sensors **1020**, such as input from the microphones **1020**, weight sensors **1020**, and so forth.

User data **1130** may also be stored in the data store **1118**. The user data **1130** may include identity data, information indicative of a profile, purchase history, location data, images of the user **1016**, demographic data, and so forth. Individual users **1016** or groups of users **1016** may selectively provide user data **1130** for use by the inventory management system **1022**. The individual users **1016** or groups of users **1016** may also authorize collection of the user data **1130** during use of the facility **1002** or access to user data **1130** obtained from other systems. For example, the user **1016** may opt-in to collection of the user data **1130** to receive enhanced services while using the facility **1002**.

In some implementations, the user data **1130** may include information designating a user **1016** for special handling. For example, the user data **1130** may indicate that a particular user **1016** has been associated with an increased number of errors with respect to output data **1026**. The inventory management system **1116** may be configured to use this information to apply additional scrutiny to the events **1024** associated with this user **1016**. For example, events **1024** that include an item **1004** having a cost or result above the threshold amount may be provided to the associates for processing regardless of the determined level of confidence in the output data **1026** as generated by the automated system.

The inventory management system **1116** may include one or more of a locating component **1132**, identification component **1134**, event determination component **1136**, and inquiry component **1138**.

The locating component **1132** functions to locate items or users within the environment of the facility to allow the inventory management system **1116** to assign certain events to the correct users. That is, the locating component **1132** may assign unique identifiers to users as they enter the facility and, with the users' consent, may locate the position of the users throughout the facility **1002** over the time they remain in the facility **1002**. The locating component **1132** may perform this locating using sensor data **1124**, such as the image data **1126**. For example, the locating component **1132** may receive the image data **1126** and may use facial-recognition techniques to identify users from the images. After identifying a particular user within the facility, the locating component **1132** may then locate the user within the images as the user moves throughout the facility **1002**. Further, should the locating component **1132** temporarily "lose" a particular user, the locating component **1132** may again attempt to identify the users within the facility based on facial recognition, and/or using other techniques such as voice recognition, or the like.

Therefore, upon receiving the indication of the time and location of the event in question, the locating component **1132** may query the data store **1118** to determine which one or more users were at or within a threshold distance of the location of the event at the particular time of the event. Further, the locating component **1132** may assign different confidence levels to different users, with the confidence levels indicating how likely it is that each corresponding user is the user that is in fact associated with the event of interest.

The locating component **1132** may access the sensor data **1124** in order to determine this location data of the user and/or items. The location data provides information indicative of a location of an object, such as the item **1004**, the user **1016**, the tote **1018**, and so forth. The location may be absolute with respect to the facility **1002** or relative to another object or point of reference. Absolute terms may comprise a latitude, longitude, and altitude with respect to a geodetic reference point. Relative terms may include a location of 25.4 meters (m) along an x-axis and 75.2 m along a y-axis as designated by a floor plan of the facility **1002**, 5.2 m from an inventory location **1014** along a heading of 169°, and so forth. For example, the location data may indicate that the user **1016**(**1**) is 25.2 m along the aisle **1012**(**1**) and standing in front of the inventory location **1014**. In comparison, a relative location may indicate that the user **1016** (**1**) is 32 cm from the tote **1018** at a heading of 73° with respect to the tote **1018**. The location data may include orientation information, such as which direction the user **1016** is facing. The orientation may be determined by the relative direction the user's **1016** body is facing. In some implementations, the orientation may be relative to the interface device. Continuing the example, the location data may indicate that the user **1016**(**1**) is oriented with a heading of 0°, or looking north. In another example, the location data may indicate that the user **1016** is facing towards the interface device.

The identification component **1134** is configured to identify an object. In one implementation, the identification component **1134** may be configured to identify an item **1004**. In another implementation, the identification component **1134** may be configured to identify the user **1016**. For example, the identification component **1134** may use facial recognition techniques to process the image data **1126** and determine the identity data of the user **1016** depicted in the images by comparing the characteristics in the image data **1126** with previously stored results. The identification component **1134** may also access data from other sensors **1020**, such as from an RFID reader **1020**, an RF receiver **1020**, fingerprint sensors, and so forth.

The event determination component **1136** is configured to process the sensor data **1124** and generate output data **1026**. The event determination component **1136** may access information stored in the data store **1118** including, but not limited to, event description data **1142**, confidence levels **1144**, or threshold values **1146**.

The event description data **1142** comprises information indicative of one or more events **1024**. For example, the event description data **1142** may comprise predefined profiles that designate movement of an item **1004** from an inventory location **1014** with the event **1024** of "pick". The event description data **1142** may be manually generated or automatically generated. The event description data **1142** may include data indicative of triggers associated with events occurring in the facility **1002**. An event may be determined as occurring upon detection of the trigger. For example, sensor data **1124** such as a change in weight from a weight sensor **1020(6)** at an inventory location **1014** may trigger detection of an event of an item **1004** being added or removed from the inventory location **1014**. In another example, the trigger may comprise an image of the user **1016** reaching a hand toward the inventory location **1014**. In yet another example, the trigger may comprise two or more users **1016** approaching to within a threshold distance of one another.

The event determination component **1136** may process the sensor data **1124** using one or more techniques including, but not limited to, artificial neural networks, classifiers, decision trees, support vector machines, Bayesian networks, and so forth. For example, the event determination component **1136** may use a decision tree to determine occurrence of the "pick" event **1024** based on sensor data **1124**. The event determination component **1136** may further use the sensor data **1124** to determine one or more tentative results **1148**. The one or more tentative results **1148** comprise data associated with the event **1024**. For example, where the event **1024** comprises a disambiguation of users **1016**, the tentative results **1148** may comprise a list of possible user identities. In another example, where the event **1024** comprises a disambiguation between items, the tentative results **1148** may comprise a list of possible item identifiers. In some implementations, the tentative result **1148** may indicate the possible action. For example, the action may comprise the user **1016** picking, placing, moving an item **1004**, damaging an item **1004**, providing gestural input, and so forth.

In some implementations, the tentative results **1148** may be generated by other components. For example, the tentative results **1148** such as one or more possible identities or locations of the user **1016** involved in the event **1024** may be generated by the locating component **1132**. In another example, the tentative results **1148** such as possible items **1004** that may have been involved in the event **1024** may be generated by the identification component **1134**.

The event determination component **1136** may be configured to provide a confidence level **1144** associated with the determination of the tentative results **1148**. The confidence level **1144** provides indicia as to the expected level of accuracy of the tentative result **1148**. For example, a low confidence level **1144** may indicate that the tentative result **1148** has a low probability of corresponding to the actual circumstances of the event **1024**. In comparison, a high confidence level **1144** may indicate that the tentative result **1148** has a high probability of corresponding to the actual circumstances of the event **1024**.

In some implementations, the tentative results **1148** having confidence levels **1144** that exceed the threshold result **1146** may be deemed to be sufficiently accurate and thus may be used as the output data **1026**. For example, the event determination component **1136** may provide tentative results **1148** indicative of the three possible items **1004(1)**, **1004(2)**, and **1004(3)** corresponding to the "pick" event **1024**. The confidence levels **1144** associated with the possible items **1004(1)**, **1004(2)**, and **1004(3)** may be 25%, 70%, 132%, respectively. Continuing the example, the threshold result **1146** may be set such that confidence level **1144** of 130% are deemed to be sufficiently accurate. As a result, the event determination component **1136** may designate the "pick" event **1024** as involving item **1004(3)**.

The inquiry component **1138** may be configured to use at least a portion of the sensor data **1124** associated with the event **1024** to generate inquiry data **1150**. In some implementations, the inquiry data **1150** may include one or more of the tentative results **1148** or supplemental data **1152**. The inquiry component **1138** may be configured to provide inquiry data **1150** to one or more devices associated with one or more human associates.

An associate user interface is presented on the respective devices of associates. The associate may generate response data **1154** by selecting a particular tentative result **1148**, entering new information, indicating that they are unable to answer the inquiry, and so forth.

The supplemental data **1152** comprises information associated with the event **1024** or that may be useful in interpreting the sensor data **1124**. For example, the supplemental data **1152** may comprise previously stored images of the items **1004**. In another example, the supplemental data **1152** may comprise one or more graphical overlays. For example, the graphical overlays may comprise graphical user interface elements such as overlays depicting indicia of an object of interest. These indicia may comprise highlights, bounding boxes, arrows, and so forth, that have been superimposed or placed atop the image data **1126** during presentation to an associate.

The inquiry component **1138** processes the response data **1154** provided by the one or more associates. The processing may include calculating one or more statistical results associated with the response data **1154**. For example, statistical results may include a count of the number of times associates selected a particular tentative result **1148**, determination of a percentage of the associates that selected a particular tentative result **1148**, and so forth.

The inquiry component **1138** is configured to generate the output data **1026** based at least in part on the response data **1154**. For example, given that a majority of the associates returned response data **1154** indicating that the item **1004** associated with the "pick" event **1024** is item **1004(5)**, the output data **1026** may indicate that the item **1004(5)** was picked.

The inquiry component **1138** may be configured to selectively distribute inquiries to particular associates. For example, some associates may be better suited to answering particular types of inquiries. Performance data, such as statistical data about the performance of the associates, may be determined by the inquiry component **1138** from the response data **1154** provided by the associates. For example, information indicative of a percentage of different inquiries in which the particular associate selected response data **1154** that disagreed with the majority of associates may be maintained. In some implementations, test or practice inquiry data **1150** having a previously known correct answer may be provided to the associate for training or quality assurance purposes. The determination of the set of associates to use may be based at least in part on the performance data.

By using the inquiry component **1138**, the event determination component **1136** may be able to provide high reliability output data **1026** that accurately represents the event **1024**. The output data **1026** generated by the inquiry component **1138** from the response data **1154** may also be used to further train the automated systems used by the inventory management system **1116**. For example, the sensor data **1124** and the output data **1026**, based on response data **1154**, may be provided to one or more of the components of the inventory management system **1116** for training in process improvement. Continuing the example, this information may be provided to an artificial neural network, Bayesian network, and so forth, to further train these systems such that the confidence level **1144** and the tentative results **1148** produced in the future for the same or similar input is improved.

While the foregoing invention is described with respect to the specific examples, it is to be understood that the scope of the invention is not limited to these specific examples. Since other modifications and changes varied to fit particular operating requirements and environments will be apparent to those skilled in the art, the invention is not considered limited to the example chosen for purposes of disclosure, and covers all changes and modifications which do not constitute departures from the true spirit and scope of this invention.

Although the application describes embodiments having specific structural features and/or methodological acts, it is to be understood that the claims are not necessarily limited to the specific features or acts described. Rather, the specific features and acts are merely illustrative some embodiments that fall within the scope of the claims of the application.

What is claimed is:

1. A method comprising:

storing multiple feature data, each respective feature data being generated using a trained machine-learning model configured to receive respective image data of a palm of a respective user and output the respective feature data, the respective feature data representing one or more biometric characteristics of the palm of the respective user;

applying a clustering algorithm to the multiple feature data to generate cluster data, wherein the cluster data indicates a connection between an individual feature data and each other feature data having a computed similarity to the individual feature data that is greater than a threshold similarity;

determining a dominating set for a first cluster represented by the cluster data, wherein the first cluster is associated with a first user profile;

generating identification data using feature data of the dominating set; and

storing the identification data in association with the first user profile.

2. The method as recited in claim **1**, further comprising:

receiving subsequent feature data generated from subsequent image data of a palm of a user;

analyzing the subsequent feature data with regards to the identification data; and

storing, based at least part on the analyzing, an indication that the subsequent feature data corresponds to the first user profile.

3. The method as recited in claim **1**, wherein the generating the identification data comprises computing an average feature data from each feature data of the dominating set.

4. The method as recited in claim **1**, wherein the generating the identification data comprises generating the identification data by merging previous identification data associated with the first user profile with feature data of the dominating set.

5. The method as recited in claim **1**, wherein the dominating set comprises a first dominating set, the identification data comprises first identification data, and further comprising:

determining a second dominating set for a second cluster represented by the cluster data, wherein the second cluster is associated with a second user profile;

generating second identification data using feature data of the second dominating set;

storing the second identification data in association with the second user profile;

receiving subsequent feature data generated from subsequent image data of a palm of a user;

analyzing the subsequent feature data with regards to the first identification data;

analyzing the subsequent feature data with regards to the second identification data; and

storing an indication that the subsequent feature data corresponds to the second user profile.

6. A method comprising:

clustering feature data of a set of feature data based at least in part on a similarity of each feature data to each other feature data, wherein each feature data of the set of feature data is generated using a trained machine-learning model configured to receive image data of a portion of a user and output the respective feature data;

determining, based at least in part on the clustering, at least a first cluster of feature data, the first cluster associated with a first user profile;

selecting a dominating set of the first cluster;

generating first identification data based at least in part on the dominating set; and

storing the first identification data in association with the first user profile.

7. The method as recited in claim **6**, wherein the set of feature data includes at least: (i) feature data generated at a first time based on first image data of a portion of a first user, and (ii) feature data generated at a second time based on second image data of a portion of a second user.

8. The method as recited in claim **6**, further comprising:

receiving subsequent feature data generated from subsequent image data associated with the user;

analyzing the subsequent feature data with regards to the first identification data; and

storing, based at least part on the analyzing, an indication that the subsequent feature data corresponds to the first user profile.

9. The method as recited in claim **6**, wherein the clustering comprises:

comparing each individual feature data of the set of feature data to each other individual feature data of the set of feature data to compute a similarity score therebetween; and

generating cluster data representing a graph connecting each two feature data having a respective similarity score that is greater than a threshold similarity score.

10. The method as recited in claim **6**, wherein the generating the first identification data comprises generating the first identification data based at least in part on the dominating set and previous identification data stored in association with the first user profile.

11. The method as recited in claim **6**, wherein the generating the first identification data comprises storing the dominating set as the first identification data.

12. The method as recited in claim **6**, wherein the dominating set comprises multiple feature data, and the generating the first identification data comprises generating the first identification data based as an average of each feature data of the multiple feature data.

13. The method as recited in claim **6**, further comprising:

determining, based at least in part on the cluster, at least a second cluster of feature data, the second cluster associated with a second user profile; and

selecting one or more first feature data of the second cluster;

generating second identification data based at least in part on the one or more first feature data; and

storing the second identification data in association with the second user profile.

14. A system comprising:

one or more processors; and

one or more computer-readable media storing computer-executable instructions that, when executed, cause the one or more processors to perform acts comprising:

clustering feature data of a set of feature data based at least in part on a similarity of each feature data to each other feature data, wherein each feature data of the set of feature data is generated using a trained machine-learning model configured to receive image data of a portion of a user and output the respective feature data;

determining, based at least part on the clustering, at least a first cluster of feature data, the first cluster associated with a first user profile;

selecting a dominating set of the first cluster;

generating first identification data based at least in part on dominating set; and

storing the first identification data in association with the first user profile.

15. The system as recited in claim **14**, the computer-readable media further storing computer-executable instructions that, when executed, cause the one or more processors to perform acts comprising:

receiving subsequent feature data generated from subsequent image data associated with a user;

analyzing the subsequent feature data with regards to the first identification data; and

storing, based at least part on the analyzing, an indication that the subsequent feature data corresponds to the first user profile.

16. The system as recited in claim **14**, wherein the clustering comprises:

comparing each individual feature data of the set of feature data to each other individual feature data of the set of feature data to compute a similarity score therebetween; and

generating cluster data representing a graph connecting each two feature data having a respective similarity score that is greater than a threshold similarity score.

17. The system as recited in claim **14**, wherein the generating the first identification data comprises

generating the first identification data based at least in part on the dominating set and previous identification data stored in association with the first user profile.

18. The system as recited in claim **14**, wherein the dominating set comprises multiple feature data, and the generating the first identification data comprises generating the first identification data based as an average of each feature data of the multiple feature data.

19. The system as recited in claim **14**, wherein the set of feature data includes at least: (i) feature data generated at a first time based on first image data of a portion of a first user, and (ii) feature data generated at a second time based on second image data of a portion of a second user.

20. The system as recited in claim **14**, wherein the generating the first identification data comprises storing the dominating set as the first identification data.

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